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AIRBORNE ASBESTOS LEVELS IN SCHOOLS

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PREFACE

This report presents the results of the collaborative effort of two primary contractors for the Exposure Evaluation Division (EED) of the Office of Toxic Substances: Midwest Research Institute (MRI) under EPA Contract No. 68-01-5915 and Research Triangle Institute (RTI) under EPA Contract No. 68-01-5948. MRI's overall responsibility was program management and sampling and analysis. RTI's overall responsibility was statistical design and data analysis. Support in field sampling, electron microscopy, and statistical analysis was provided under subcontract by Battelle Columbus Laboratories (BCL); and in quality assurance analyses of field samples under subcontract by Illinois Institute of Technology (IITRI) and Colorado School of Mines Research Institute (CSMRI).

The work reported on herein is of a task under the EPA program entitled "Sampling and Analysis of Selected Toxic Substances." This program is under the leadership of Dr. John E. Going and was under the overall management of Dr. James L. Spigarelli, Director of the Analytical Chemistry Department of Midwest Research Institute. Mr. Steven R. Williams was RTI's program manager.

The MRI work was conducted under the technical management of Mr. Paul C. Constant, Jr. He was assisted by Mr. Fred J. Bergman, who supervised field sampling activities. Ms. Teresa Costello, Ms. Kim Cowherd, Ms. Marilyn Gabriel, Mr. Mike Kalinoski, Ms. Lily Leong, Mrs. Donna R. Rose, and Ms. Carolyn Winter were MRI's field personnel. Mr. Bergman and Mrs. Rose were field crew leaders. Mr. Gaylord R. Atkinson was responsible for the analysis of the bulk samples. He was assisted by Mrs. Rose. Dr. Dennis Takade was the quality assurance coordinator and also performed the sample and traceability audit. Mr. John Hosenfeld assisted Dr. Takade. The BCL subcontract with MRI was managed by Dr. Charles W. Townley. The late Mr. Eric Schmidt was responsible for BCL's field sampling. His field samplers were Mr. Curtis Bridges, Mr. Gregory L. Headington, Mr. Salo E. Miller, and Ms. Amanda Bush Osburn. Mr. Julius S. Ogden was responsible for the analysis of the air samples. He was assisted by Mrs. Sandra J. Anderson, Mrs. Carolyn F. Dye, Mrs. Irene E. Green, Mr. Doyle F. Kohler, and Mr. Carl W. Melton. Dr. Bertram P. Price provided the statistical assistance at BCL.

The RTI work was conducted under the supervision of Dr. Tyler D. Hartwell, who also was responsible for the statistical analysis. He was assisted with the statistical analyses by Dr. Donna L. Watts and Dr. Everett E. Logue. Dr. Watts was responsible for the survey design and selection of sites. She was assisted by Ms. Denise Melroy. The statistical data file audit was performed by Ms. Debbie Whitehurst.

The rater team that inspected the sampling sites to obtain consensus ratings of specific aspects of the asbestos-containing material and the site included Dr. Joseph J. Breen and Ms. Cindy R. Stroup of EED, Dr. Everett Logue of RTI, and two persons from the school district surveyed.

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency's Office of Toxic Substances has an ongoing asbestos-in-schools program. As part of this program, a study was conducted in a large, urban U.S. school district to: (1) document exposures to airborne asbestos resulting from friable, asbestos-containing materials in schools and (2) validate existing exposure assessment tools (including the algorithm) and determine relationships between asbestos air levels and individual or combined assessment factors. The study covered five major areas of work: the development of a survey design, the design of a quality assurance plan, the execution of a field survey, the chemical analysis of field samples, and the statistical analysis and interpretation of data.

The survey plan was based on a sample design that allows valid inferences to be made for the field study area concerning airborne asbestos levels and the relationships between these levels and the assessment tools or individual factors and combinations. The study sites were randomly selected from all the student activity areas of schools in the school district that contained asbestos materials. Data concerning auxiliary variables such as room dimensions, floor covering (carpeted, tile, wood), cleaning practices, air conditioning, and room temperature were collected in addition to air and bulk samples.

A detailed statistical analysis of the data collected was undertaken. The main intent of this analysis was first to document the asbestos air levels, bulk asbestos levels, assessment factors, and algorithm scores in the school district and then to examine various relationships. In particular, it was of interest to determine how well airborne chrysotile levels could be predicted by the assessment factors, singly and in combination.

The quality assurance plan covered all aspects of the study: the objective of the plan, personnel and their responsibilities, and field and laboratory compliance requirements such as standard operating procedures, protocols, monitoring, documentation, and communications. Protocols were prepared and followed on air sampling, sampling and analysis of insulation material suspected of containing asbestos, chemical analysis of air samples, and chain of custody of samples. External quality assurance analyses were performed on both air and bulk samples. The results of complete audits performed on all data were satisfactory.

A total of 48 asbestos-containing sites in 25 schools were sampled for airborne asbestos. The air was monitored for five consecutive days at each school while students were present. At each school, an outdoor ambient sample, an indoor control sample from an area without asbestos-containing material, and up to four indoor samples from student activity rooms that contained asbestos material were collected simultaneously.

The total of 116 air samples and 9 blank filter samples were collected. They were analyzed by transmission electron microscopy (TEM) techniques for asbestos fiber concentration. The mean airborne asbestos levels for the three types of sites studied are:

Site	Mean (ng/m^3)	Standard error of the mean
Asbestos-containing material	179	42
Indoor control	53	20
Outdoor ambient	6	4

The statistical test of difference in air level means among the three types of sites is significant at the level < 0.01.

To investigate the variability of airborne asbestos with time, 3 of the 48 sites were selected for long-term study (three consecutive school weeks). There is evidence of substantial variation over time in airborne asbestos levels in the same room. For the current data, this variation was approximately 100% (i.e., the coefficient of variation over 3 weeks = standard deviation/mean = 100%).

Three bulk samples were collected from each of the 48 asbestos-containing sites. In addition, one double sample (taken side-by-side) was collected at each site to provide a duplicate for quality assurance. A total of 192 bulk samples were collected for fiber analysis by polarized light microscopy (PLM) techniques. The asbestos (chrysotile) content ranged from 5 to 63% with a mean of 16%.

In addition to standard PLM analysis, the bulk samples were examined for physical characteristics that could be of importance. There were three major matrix components (perlite, vermiculite, and glass wool), three dominant fiber sizes (fine, medium, and coarse), and two fiber coat categories (coated and not coated). Based on this analysis, a fiber releasability rating system was developed. Bulk samples were rated according to how readily the asbestos fibers would be released from the bulk material. The releasability ratings at each site were compared to the airborne asbestos level at that site. The results of the comparisons demonstrated a relationship between the bulk sample releasability rating and the airborne asbestos levels; i.e., a high releasability rating corresponded to elevated airborne asbestos levels.

Each of the 48 sites selected for the study was rated by a five-member panel on the following assessment factors: material condition, accessibility, whether it is part of an air moving system, how much of the material is exposed, presence of water damage, activity level, and degree of friability. The panel of raters first independently rated each site. Then, a consensus rating was determined for each factor. A comparison between the consensus and the individual independent ratings found good agreement. The consensus ratings were reported and used in the statistical analysis of the relationship between factors and measured concentration levels of airborne asbestos.

The factors material condition, accessibility, activity, and friability were not related to airborne asbestos levels for these data. The factor combinations available in the school district were limited. For example, almost all activity areas were greater than 10% exposed; no sites were found where the condition was rated "severely damaged"; and no sites were found where accessibility was rated "not accessible."

The principal conclusions related to the first study objective are: (1) airborne asbestos levels inside school buildings with asbestos are significantly higher than outdoor ambient levels due to the release of asbestos fibers from asbestos-containing materials inside those buildings; and (2) within a school building, asbestos fibers are transported from rooms having asbestos-containing materials to rooms without these materials.

The principal conclusions related to the second study objective are: (1) the existing algorithm is not a valid predictor of exposure to airborne asbestos levels; (2) the amount of asbestos in the bulk material is not a valid predictor of exposure to airborne asbestos levels; (3) the releasability rating system developed in this study is related to levels of airborne asbestos. (Additional studies are underway to attempt to validate this system.)

SECTION 1

INTRODUCTION

The widespread use of asbestos over the years has raised the issue of increased cancer and chronic respiratory disease risk in various segments of the population. Pulmonary cancer, mesothelioma, and fibrosis of the lung are known to be associated with exposure to asbestos in certain work places, such as where asbestos is mined and milled or where asbestos materials and products are manufactured or used (NCI 1978, Peto et al., 1982, Zivy 1982). Currently there is considerable concern that asbestos-containing materials that were used extensively in schools from 1945 to 1973 for fire-retarding purposes and acoustical insulation are deteriorating or being disturbed, with the release of asbestos fibers into the air of the buildings. The resultant exposure of the students, teachers, and school staff to the airborne asbestos may result in asbestos-related diseases. A rule proposed by the U.S. Environmental Protection Agency (EPA) requiring the identification of friable asbestos-containing materials in schools and the notification of those exposed to the materials was published in the Federal Register (45 FR 61966) in September 1980. The final rule was published May 27, 1982, in the Federal Register (47 FR 23360) and was effective June 28, 1982.

The Exposure Evaluation Division (EED) of EPA's Office of Toxic Substances (OTS) has been providing a variety of technical support to the OTS asbestos-in-schools program since its inception. This support includes the development of sampling and analytical protocols; guidance for quality assurance programs appropriate for implementation at state and local levels; a PLM analytical proficiency program for laboratories analyzing bulk samples; international collaborative work with Laboratoire d'Etude des Particules Inhalées, Paris, on the collection and analysis of bulk samples and their relation to airborne asbestos levels; preparation of an photomicrographic asbestos particle atlas; preparation of a design study for a field survey to collect data on airborne asbestos levels and the physical characteristics of the bulk materials; and the investigations of exposure rating systems designed to identify buildings that have significant airborne asbestos exposures.

Two procedures that have been proposed for characterizing airborne exposures are the algorithm and the decision tree, both of which are discussed in detail in Appendix A. The usefulness of both these procedures in assessing exposure has been an ongoing concern to EPA. Over the past 2 years, there have been a number of investigations directed at validating assessment tools (USEPA 1979a, USEPA 1981a). The experience gained has resulted in a field study design that proposed air sampling to validate these procedures (Price et al. 1980). A design report addressing the statistical aspects of the study design including expectations for precision in the final results was prepared as an aid in the planning process (USEPA 1981c).

That design was the basis for the field study presented in this report. The field study had two objectives:

1. To document exposures to airborne asbestos resulting from friable asbestos-containing materials in schools.

2. To validate existing exposure assessment tools (including the algorithm) and determine relationships between asbestos air levels and individual or combined assessment factors.

These objectives were addressed by surveying the school buildings of a large urban school district. The principal conclusions of the study are given in Section 2. The overall quality assurance program that was used is described in Section 3. A discussion of the sample design which was the basis for the survey is given in Section 4. A discussion of the field survey, which covers all aspects of the air-sampling and the bulk sampling activities, is given in Section 5. Discussions of the transmission electron microscopy (TEM) techniques and the polarized light microscopy (PLM) techniques that were used to analyze the air and bulk samples respectively are given in Section 6. The results from these analyses are summarized in Section 6 also. A discussion of the statistical analyses that were used and their results are given in Section 7. A list of pertinent references is given at the end of Section 7.

Appendixes A through G present the study background, the sampling protocol for air sampling, the protocol for creating and maintaining chain of custody of the samples, the protocol for the sampling and the analysis of insulation material suspected of containing asbestos, the analytical protocol for air samples, copies of the data sheets that were used in rating sites on each algorithm factor, and additional statistical analyses.

SECTION 2

CONCLUSIONS

The principal conclusions from this study are given below. The first conclusion meets the first objective, which is to document potential exposures to airborne asbestos from asbestos-containing material. The second conclusion further supports this objective. The third, fourth, and fifth conclusions meet the second objective, which is to validate existing exposure assessment tools and determine relationships between asbestos air levels and individual or combined exposure factors.

1. Airborne asbestos levels in buildings with asbestos-containing materials are greater than outdoor ambient levels due to the release of asbestos fibers from those materials. On the average, the higher levels were found in rooms with asbestos-containing materials, relatively lower levels were found in rooms without asbestos-containing materials (indoor controls), and the lowest levels were found in ambient sites on the schools' roofs. Tests of significance found the average levels in the three types of sites to be significantly different (.01 level).

2. Within a school building, asbestos fibers are transported from rooms having asbestos-containing materials to rooms without these materials. There is evidence of schoolwide elevated airborne asbestos levels in more than half of the schools sampled. This was demonstrated by airborne asbestos levels in indoor control rooms that were significantly higher than ambient levels.

3. The existing algorithm is not a valid predictor of exposure to airborne asbestos levels. When the algorithm scores for the 48 sites were compared with the airborne asbestos level, the Pearson correlation coefficient was found to be -0.17 (P-value = 0.25).

4. The amount of asbestos in the bulk material is not a valid predictor of exposure to airborne asbestos levels. When the average percentages of the asbestos in the bulk materials in the 48 sites were compared with airborne asbestos levels, the Pearson correlation coefficient was found to be -0.06 (P-value = 0.71).

5. The releasability rating system that was developed in this work is related to airborne asbestos levels in the school district examined. When the releasability ratings of the 48 sites were compared with the airborne asbestos levels, the Spearman correlation coefficient was found to be 0.44 (P-value = < 0.01). (Releasability is based on microscopic characterization of the bulk material and is discussed on page 78.)

SECTION 3

OVERALL QUALITY ASSURANCE PROGRAM

Quality assurance was an important consideration in the execution of this study. It covered the organization of the team and the operation of all aspects of the work. The major components of the quality assurance program are summarized below.

I. ORGANIZATION

This was a collaborative study for EPA's Office of Toxic Substances (OTS) that was performed under two prime contracts. Midwest Research Institute (MRI), under EPA Contract No. 68-01-5915, was a prime contractor who worked for the Field Studies Branch of the Exposure Evaluation Division of OTS. Research Triangle Institute (RTI), under EPA Contract No. 68-01-5848, was a prime contractor who worked for the Design and Development Branch of the same division.

There were eight major areas of activities: management, survey design, statistical sampling, quality assurance, field survey, sample analysis, statistical analysis, and final report preparation. The division of responsibility was: MRI--management, quality assurance, field survey, sample analysis, and final report preparation; RTI--survey design, statistical sampling, quality assurance, statistical analysis, and report preparation. Battelle Columbus Laboratories (BCL), under subcontract, had the responsibility for the analysis of the air samples that were collected. BCL assisted MRI with the field survey and assisted RTI with survey design, statistical analysis, and data interpretation. Other MRI subcontractors were the Illinois Institute of Technology Research Institute (IITRI), who performed quality assurance analysis of air samples, and the Colorado School of Mines Research Institute, who performed quality assurance analysis of bulk samples. MRI, RTI, and BCL collaborated in the preparation of this report.

II. OPERATION

The study was initiated with a planning meeting with EPA, MRI, RTI, and BCL personnel. The mission of the study, which is given in Section 1, was well understood by all parties. The plan of operations was established and specific assignments and responsibilities were made. This four-party team worked together closely throughout the study.

In the execution of the plan all field and laboratory compliance requirements and a thorough documentation system were followed. Good communications via telephone conversations, meetings, written communiques, and reports were maintained among all parties. Plans were modified as required for effectiveness of operation.

Protocols were prepared to ensure uniformity in sampling and chemical analysis. Quality assurance data were collected in order to monitor the data acquisition process. A chain of custody was established and quality assurance audits were conducted to ensure that all procedures were followed. The quality assurance program is briefly summarized in the paragraphs that follow. Evaluation of quality assurance data on sampling and chemical analysis are found in the sections treating those topics, Sections 5 and 6, respectively. Details of the protocols are found in the Appendices B through E.

A. Protocols

Existing protocols were adapted when possible. The EPA bulk sampling and quality assurance protocol (USEPA 1980b) was followed and is summarized in Appendix D. The protocol for analyzing bulk samples for asbestos content specifies the use of PLM and closely follows the steps given in the Asbestos Particle Atlas that was prepared by Walter C. McCrone (1980) and the EPA PLM analytical protocol (USEPA 1982b, 1980 draft version). The protocol for TEM analysis of filters (Appendix E) generally follows an EPA method (USEPA 1978). The protocol specifies sample preparation, fiber counting, and units conversion to nanograms per cubic meter.

A chain of custody (Appendix C) was developed both for the handling of air samples taken on filters and for bulk samples. The chain of custody was implemented to ensure that data being reported are in fact data from those samples that were taken in the field. It also allowed the renumbering of samples prior to chemical analysis to prevent analyst bias from affecting the results.

A protocol for collecting air samples was also developed and is described in Appendix B. It provides guidance for placing the sampler, specifies the type of sampling equipment to be used, and specifies the sampling operating characteristics including flow rate, sampling time, and other basic parameters. The protocol for collecting bulk samples (Appendix D) specifies how to define a sampling area and how to select appropriate locations for sampling.

B. Quality Assurance Data

For TEM analysis of filters, data were obtained on laboratory blanks and field blanks. A portion of the filters were selected at random for duplicate analysis, and other filters were divided for analysis at an independent laboratory.

The detection limit for the TEM analysis is one fiber observed while scanning grid openings. The resulting detectable quantity, based on the protocol and the volume of air sampled, is 0.002 ng/m^3. The quantification limit depends on the number of fibers observed during the TEM analysis, which was 1 to 941. Thus, the number of significant figures for the TEM results ranges from 1 to 3.

For the PLM analysis of bulk samples, side-by-side samples were divided into two groups at random. One group was used to assess intralaboratory variation; the other group was split between the primary and a secondary laboratory to investigate interlaboratory variation.

Further information on TEM and PLM quality assurance analyses can be found in Section 6.

C. Audits

Traceability audits were conducted (1) to determine and establish sample and data traceability and (2) to determine if sampling and analysis protocols were followed. The audit results indicated that all bulk samples were traceable, and sampling and analysis were performed according to designated protocols. All air samples except one were traceable. This one air sample was one of a group that was put on hold pending recycling of the sites for samples of longer durations of sampling. The repeat sample was used; therefore, the one not traceable was not needed. Inconsistencies in fiber counts were discovered. Records were corrected, and air-level calculations were repeated to eliminate the inconsistencies. This resulted in over 20 revisions in air levels. Sampling and analysis were completed according to protocol.

An audit was also conducted on the data file that was prepared for statistical analysis. The objectives of the audit were to verify all data values and to verify that the data were correctly identified with the school and the sampling area within the school. The results indicated one minor error in the averaging of the percent asbestos for bulk samples from a site. The error was corrected, and it was determined that the change was of no material importance to the results of the statistical analysis.

D. Site-Specific Ratings

The sites where air sampling and bulk sampling took place were inspected by a panel of five trained raters. Their primary purpose was to obtain consensus ratings of the assessment factors (Appendix A). The consensus ratings were obtained at each site by polling the five raters after all raters had recorded their independent assessment of the factors on a data sheet. A simple majority rule was invoked when there was disagreement among the five independent assessments. The results of the statistical analyses of this information are given in Section 7.

SECTION 4

SAMPLE DESIGN AND SELECTION

This section outlines the sample design and selection for this study of airborne asbestos levels. A more detailed description of the design (USEPA 1981c) and its development is provided in Appendix A.

The study population, or population of inferential interest, was defined in terms of all student activity areas in the study school district. The study population consisted of student activity areas that had asbestos-containing material. The sample design was developed to satisfy the informational requirements of the study for this population. The first objective of the study was to document potential exposure to airborne asbestos in schools in which asbestos-containing materials were present. This objective required estimating airborne asbestos levels at these sites and comparing these estimates with estimates for the following types of sites: (1) student activity areas without asbestos-containing material, or control sites, and (2) outdoor ambient sites. To ensure estimates of the desired precision, the sample design controlled the distribution of the sample with respect to these types of sites.

The second objective of the study was to examine the relationship between asbestos air levels and individual or combined assessment factors (including the algorithm). This second objective required estimating and comparing airborne asbestos levels of the sites with different assessment factor level combinations. The sample design controlled the distribution of the sample with respect to certain assessment factor level combinations.

These two study objectives were mutually conflicting as to the prescribed allocation of sites among the factor level combinations; that is, the allocation that was to give the most precise estimates for the first objective was not the same as the allocation that was to give the most precise estimates for the second objective. This was because the factor level combinations of interest were not present in equal proportions in the study population. To satisfy the study objectives, the sample design employed a compromise allocation.

The sample design, outlined below, was a two-stage design with stratification imposed on each stage. First-stage sampling units were schools having asbestos-containing material in student activity areas. Second-stage sampling units were student activity areas, or sites (e.g., classrooms, auditoriums, and gymnasiums). A total of 48 asbestos-containing material sites were selected in 25 sample schools. Additionally, one control site (a site without asbestos-containing material) was selected from each of the 25 schools in the first-stage sample.

At each of the 48 asbestos-containing material sites, the following activities were to be conducted: (1) air sampling during five consecutive school days while students were in attendance, (2) bulk sampling of asbestos-containing material, (3) scoring assessment factors, and (4) collecting other relevant site information (e.g., cleaning procedures used and weather conditions during air sampling). The field activities are described in detail in Section 5 of this report. With the exception of bulk sampling, the above activities were also performed at the 25 control sites. Additionally, air sampling was conducted outside each of the 25 schools. At three sites randomly selected from the 48 asbestos-containing material sites, air sampling was to be conducted during three consecutive periods of five school days; concurrently, air sampling was conducted at the control sites and at outdoor ambient sites associated with these three sites.

The sample design employed for this study was a statistically valid design that permitted estimation for the study population free from selection bias. (Bias refers to the average difference between estimated values and the true value of a given parameter for the population of interest.) Using a probability sample design with demonstrable inferential ability for the study area was one aspect of the overall effort to ensure data quality for this study. A purposive selection of schools and sites within schools was not used because it would not permit statistically valid inferences to be made for the study population; the results would apply only to those sites where data were collected. Also, there would be little assurance that the results were not influenced by researcher preconceptions or objectives.

Because this study was of a geographically restricted area, as opposed to a national study, the inferential ability of the information generated by the study was concomitantly restricted. It was still thought important, however, that a probability sample design be employed to allow conclusions to be drawn at the level of the study population. The study population was a real-world collection of sites that might well be typical of many other settings. An examination of the population frequencies of assessment factor combinations suggested that this school district is similar in that regard to other school systems.

I. STUDY POPULATION

The study population consisted of all the school district's student activity areas, or eligible sites, in schools that had asbestos-containing material in any student activity area. Eligible sites within a school included classrooms, corridors, gymnasiums, locker rooms, cafeterias, kitchens, libraries, and auditoriums. The term "classroom" also refers to special purpose rooms such as music rooms and laboratories. The following school areas were not considered to be eligible sites: administrative offices, teachers' lounges, custodial rooms, storage rooms, mechanical rooms, and restrooms. This definition of which sites are eligible for the study was based on an interest in sites with higher activity levels and an interest in exposure of students to airborne asbestos. Restrooms were not considered eligible sites because they were not thought to be operationally feasible.

A major reason for conducting the study in this particular school district was that, through its own asbestos program, the district had collected information that could be used to advantage in the selection of sites. School personnel had recently inspected all the district's schools for asbestos-containing material. In schools where material suspected of containing asbestos was found, the total area was partitioned into sampling areas according to the USEPA procedure (1980b, 1980c). Bulk samples were taken and data on the assessment factors were collected.

The school personnel's inspection produced 134 eligible sampling areas. At the time the sample was selected, laboratory analyses of bulk samples had been reported for 92 of these sampling areas. Table 1 shows the distribution of eligible sampling areas with respect to asbestos content, friability, condition, exposure, and accessibility based on the ratings by school district personnel. According to these ratings, the district's eligible sampling areas exhibited only 10 of the 32 possible combinations of the factor levels shown in Table 1. The fact that many of the factor level combinations appeared not to be present in the study population limited the comparisons that could be made to satisfy the second objective of examining the relationships of the assessment factors to airborne asbestos levels. However, factor level combinations that occurred very infrequently in real-world settings were not of major interest to this study.

II. SAMPLE DESIGN

The sample design employed was a two-stage design with stratification imposed on both stages. The first-stage frame consisted of all schools having student areas in which material known to or suspected of containing asbestos was present. The first-stage frame was stratified into nine classes formed by combining three categories of asbestos content--low, high, and unknown--with three categories of friability--low, moderate, and high. Schools were classified according to the asbestos content and friability of the sampling areas. The first-stage sample of 25 schools was allocated among the nine strata approximately in proportion to size but with greater emphasis on known asbestos content and high asbestos content. Size measures based on school enrollment were used. The required number of schools was selected from each stratum with probability proportional to size and without replacement.

The second-stage frame consisted of all eligible sites in the first-stage sample of 25 schools. The second-stage frame was stratified according to presence or absence of asbestos-containing material. Forty-eight asbestos-containing material sites and 25 control sites (sites with no asbestos-containing material) were selected. To the extent possible and given the following restrictions, the second-stage sample of 48 asbestos-containing material sites was allocated among schools and assessment factor categories proportional to the number of sites: (1) at least one site must be selected from each of the 25 schools in the first-stage sample, and (2) at least one site must be selected from each nonempty, factor combination category. Eligible asbestos-containing material sites in each school (or school and factor combination category) were listed in order according to location. The required number of sites was then selected by random systematic sampling.

Table 1. Distribution of Eligible[a] Sampling Areas in School District with Respect to Asbestos Content, Friability, Condition, Exposure, and Accessibility[b]

Asbestos content[c]	Friability[d]	Condition[e]	Exposure[f]	Accessibility[g]	No. of eligible[a] sampling areas
Low	Low	Good	Low	Low	0
Low	Low	Good	Low	High	0
Low	Low	Good	High	Low	11
Low	Low	Good	High	High	0
Low	Low	Bad	Low	Low	0
Low	Low	Bad	Low	High	0
Low	Low	Bad	High	Low	0
Low	Low	Bad	High	High	0
Low	High	Good	Low	Low	0
Low	High	Good	Low	High	0
Low	High	Good	High	Low	49
Low	High	Good	High	High	5
Low	High	Bad	Low	Low	0
Low	High	Bad	Low	High	0
Low	High	Bad	High	Low	6
Low	High	Bad	High	High	1
High	Low	Good	Low	Low	0
High	Low	Good	Low	High	0
High	Low	Good	High	Low	2
High	Low	Good	High	High	0
High	Low	Bad	Low	Low	0
High	Low	Bad	Low	High	0
High	Low	Bad	High	Low	0
High	Low	Bad	High	High	0
High	High	Good	Low	Low	0
High	High	Good	Low	High	0
High	High	Good	High	Low	13
High	High	Good	High	High	3
High	High	Bad	Low	Lo	0
High	High	Bad	Low	High	0
High	High	Bad	High	Low	1
High	High	Bad	High	High	1

(continued)

Table 1 (continued)

Asbestos content[c]	Friability[d]	Condition[e]	Exposure[f]	Accessibility[g]	No. of eligible[a] sampling areas
Unknown	Low	Good	Low	Low	0
Unknown	Low	Good	Low	High	0
Unknown	Low	Good	High	Low	1
Unknown	Low	Good	High	High	0
Unknown	Low	Bad	Low	Low	0
Unknown	Low	Bad	Low	High	0
Unknown	Low	Bad	High	Low	0
Unknown	Low	Bad	High	High	0
Unknown	High	Good	Low	Low	0
Unknown	High	Good	Low	High	0
Unknown	High	Good	High	Low	34
Unknown	High	Good	High	High	2
Unknown	High	Bad	Low	Low	0
Unknown	High	Bad	Low	High	0
Unknown	High	Bad	High	Low	4
Unknown	High	Bad	High	High	1
				Total	134

a A sampling area was eligible for study if it contained at least one eligible site with material suspected of containing asbestos. Eligible sites within a school included classrooms, corridors, gymnasiums, locker rooms, cafeterias, kitchens, libraries, and auditoriums. The following were not considered eligible sites: administrative officers, teachers' lounges, custodial rooms, storage rooms, mechanical rooms, and restrooms.

b Based on sampling area ratings by school district personnel. Asbestos content was taken from the school district's asbestos program laboratory results, reported by June 26, 1981.

c Asbestos content: Low = > 1% and < 20%, High = ≧ 20%

d Friability: Low = 1, High = 2,3

e Condition: Good = 0,2, Bad = 5

f Exposure: Low = 1, High = 4

g Accessibility: Low = 0,1, High = 4

At each of the 25 schools in the first-stage sample, one control (indoor ambient) site was also selected from the list of sites without asbestos-containing material. All such sites within a sample school had equal probability of being selected. Any student activity area without asbestos-containing material was eligible to be a control site; there was no requirement that control sites be a certain distance from asbestos-containing material sites. Additionally, the sample schools varied widely as to the proportion of the school area having asbestos-containing material.

Alternate sites were named for each of the selected sites so that field personnel could substitute an alternate site whenever a selected site was found to be ineligible (contrary to floor plan information) or whenever there was nonresponse at a selected site. Nonresponse could occur, for example, if a teacher or school official would not permit air sampling at the selected site or if air sampling was not possible at the site because of the lack of an electrical outlet, repeated vandalism, etc. An alternate site could not be substituted for a selected site simply for convenience. The procedures for substitution were carefully followed by field personnel.

SECTION 5

FIELD SURVEY

The survey included two types of sampling: air sampling, which was performed by MRI and BCL, and bulk sampling, which was performed by MRI. The air sampling activity started on May 4, 1981, and ended on June 2, 1981. The bulk sampling started on May 28, 1981, and ended on June 4, 1981. The air sampling period was fixed because the sampling had to be done while students were in school. RTI selected the sites to be surveyed. The statistical basis for the field survey plan was discussed in Section 4. The protocols that were followed for the air sampling activity and bulk sampling can be found in Appendices B and D. These protocols are adaptations of those used by Laboratoire d'Etude des Particules Inhalées, Paris (USEPA 1980f).

I. AIR SAMPLING

Forty-eight indoor sites in which asbestos-containing material was present were selected for air sampling in the 25 study schools. To investigate the variability of airborne asbestos with time, three long-term sites were randomly selected from the 48 sites.

The survey plan called for the collection at each school of one outdoor ambient air sample,* one indoor control air sample from an area constructed with materials not containing asbestos, and up to four samples from rooms that contained asbestos. All samples at a school were to be collected simultaneously. Long-term air sampling at three schools consisted of repeating the sampling procedure two additional times at the outdoor ambient site, the indoor control site, and one indoor sample site.

The air sampling phase consisted of collecting a sample at each site for five consecutive school days during school hours while students were present. The sampling rate was to be approximately 5 liters/min, for a total volume of air to be sampled of approximately 10 m^3.

* The term "sample" used in the discussion of the field survey and fiber analysis activities is not to be confused with the term "sample" that is used in the statistical sense. In the statistical discussions, "sample" refers to the subset of units selected. In this section, "sample" refers to the air or bulk material collected for chemical analysis.

A. Sampling System

The air sampling system used is shown in Figure 1. A programmable timer was set to start the system at the beginning of the class day and to stop the system at the end of the class day. The sampled day ran from 8:30 AM to 3:30 PM in elementary schools and junior high schools and from 8:00 AM to 3:00 PM in senior high schools, for a total of 7 hr/day. At sites where the system was started on days other than Monday, the timers were set to skip Saturday and Sunday, resume on Monday, and stop after five consecutive school days had been sampled.

Observation of the sampling systems during the first several days of sampling revealed that in setting the on-off stops on the timer, diaphragm pumps started and stopped from 15 min early to 15 min late. If the total volume were calculated from the timer setting, the cumulative error could be as much as 15%. It was decided to add running time meters to the sampling system to eliminate this potential source of error. Electric clocks, which were readily available, were used (running time meters could not be located). This permitted determining the actual time sampled provided sampling was not interrupted.

B. Field Operations

An air sampling scheme staggered over time was used to survey the 25 schools in accordance with the sampling protocol presented in Appendix B. During field operations some of the samples were lost and some were collected for an inadequate or unknown length of time. These deficient samples resulted from filters being vandalized, equipment theft, equipment failures, power interruptions, and field crew errors.

In an effort to obtain satisfactory samples for as many sites as possible, repeat sampling, or recycling of the deficient sample sites, was pursued. Because of the limited time available before the end of the school year, it was apparent that all deficient sample sites could not be recycled. Whenever possible, recycling was done so that all sites at a school were sampled simultaneously. A list of sites that did not meet the program criteria was prepared, and as equipment became available those sites showing the greatest deviations were recycled first. Priority was given to sites where samples had not been obtained initially. Next priority was given to sites where sampling had been less than the required 5 days, with sites ranked according to the time sampled--shortest periods to longest periods. At those sites where a 5-day sample could not be collected before the end of the school year, two samples (filters) were collected. This was accomplished by operating the sampling system until the last day of school. The filter was then recovered and a new filter was installed. The sampling system was then operated with the second filter installed until five days of sampling were completed. A hold-for-analysis label was placed on the recycled samples. At the completion of field sampling, all samples were reviewed and those most nearly meeting the program criteria were released for analysis. The remaining filters were put on hold.

Each field team member was given a logbook for recording data. Most of the type of data collected is given in the sampling protocol document

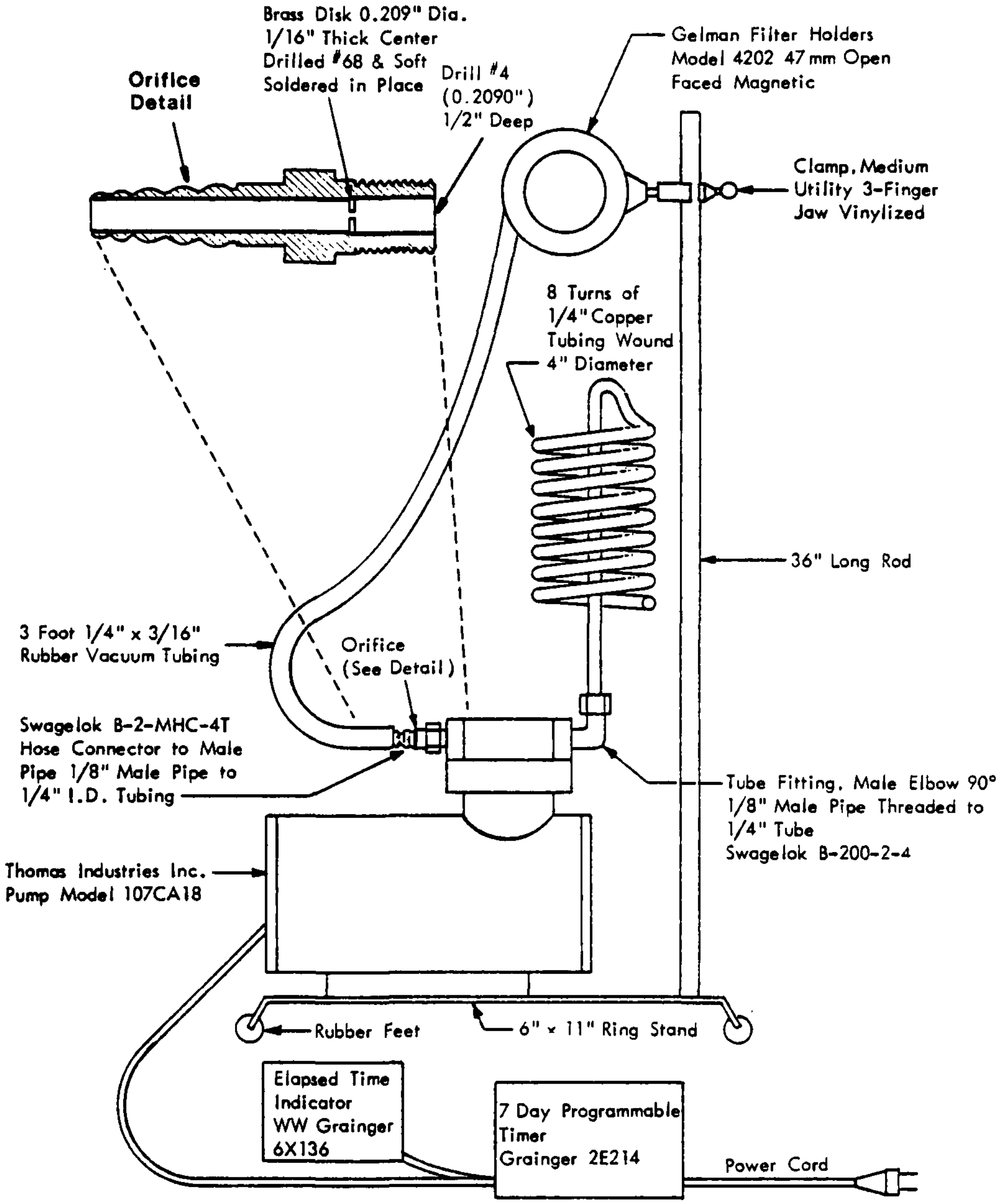

Figure 1. Air sampling system.

(Appendix B). Additional items recorded included the relative humidity and temperature at each site at the beginning and end of the sampling period, whether the air conditioner was running during the sampling period, whether a window was open, whether there was a rug or other floor covering at the sample site, and the frequency and method of cleaning the classroom and hallway where the sampler was located. To document the sampling times, the electric clock readings were recorded, and to identify the equipment used at a site, property tag numbers were recorded. Black and white photographs were taken of sampling sites. Climatological data for the area and period in which air sampling took place were obtained from the National Oceanic and Atmospheric Administration.

Because of the number of problems that developed in keeping the sites operational for the five-day period, a walk-through procedure was instituted after the first week. This procedure consisted, as time was available, of walking through each active school and observing each system. As problems with a system developed, corrective action was taken, including re-plugging in the power cords, resetting timers, exchanging or replacing missing or malfunctioning equipment, and reconnecting the hoses to the sampling heads. If filters were damaged early in the sampling period, new filters were installed and sampling was continued. At one school where several sampling systems had been tampered with, all sites at this school were recycled. During the walk-through operation and near the middle of the sampling period (between two and three days after sampling was started), and whenever possible, the temperature, relative humidity, and airflow in the sampling system were taken at each site.

C. Sample Handling

The air samples were handled according to the protocol given in Appendix C. To facilitate sample tracking, the filter holder labeling number was modified from that given in the protocol. Each modified number contained the letter "B" (for Battelle Columbus Laboratories) or "M" (for Midwest Research Institute) to designate the organization collecting the sample, followed by the operator's initials and the sample number. The sample numbers were assigned sequentially by each operator to the filters he or she recovered. At this time, the operator entered the sample number in the logbook for the collection site and completed a chain-of-custody form.

II. BULK SAMPLING

Four bulk samples were collected from each of the 48 indoor asbestos-containing sites. Samples were collected from three randomly selected points at each site. A double sample taken side by side was collected at one of the three points to provide a duplicate for quality assurance.

At the time the statistical selection of sampling points was made, all room dimensions were not available to RTI. Some of the sampling points were identified, therefore, as a fraction of the room length and width. The field sampling team located a sampling point by measuring the room and converting the fractional value to a unit of measure. If the sampling point could not be reached because of its location (above a light fixture or other obstruction), RTI was contacted for an alternate sampling point.

A. Sample Collection

Bulk samples were collected by cutting away a section of the asbestos-containing material. A section of material 1 to 8 cm^3, depending on the condition and thickness of the material, was collected. The collected samples were placed directly into labeled, snap-covered plastic bottles for shipment to MRI. At the same time, chain-of-custody forms were prepared and the sample number and site description were entered in the logbook.

B. Sample Handling

The bulk samples were transported to MRI and released to a quality control representative, who logged them in and assigned them permanent numbers on a random basis. The quality control representative then identified and removed the duplicates and, from this set of duplicates, chose, on a random basis, a number of them for external quality assurance analysis. The remaining duplicates were put with the remaining samples, and all of these were given to MRI analysts to be analyzed. Further details of the bulk sampling procedure can be found in the sampling protocol presented in Appendix D.

III. CHAIN OF CUSTODY

The protocol used for creating and maintaining the chain of custody of bulk and air samples is given in Appendix C. At the end of each week, MRI gave its chain-of-custody forms and the filters it had collected to BCL field personnel, who transported the air samples and the chain-of-custody forms to Battelle Columbus Laboratories where the samples were analyzed. At the completion of the bulk sampling, all the bulk samples and the chain-of-custody forms were transported by MRI field personnel to MRI. At MRI the QA samples were removed and sent by air to the Colorado School of Mines for analysis. The remaining samples were analyzed at MRI.

IV. SITE-SPECIFIC RATINGS

After the air sampling and the bulk sampling components of the data collection effort had been completed, a third site-specific component of the data collection effort was undertaken. Five raters walked through each room or area where both air and bulk samples were collected and recorded their structured assessments of physical characteristics of the site on specially designed data collection forms (Appendix F). In addition, one of the raters interviewed available school personnel about typical cleaning practices relevant to the sites in each school.

The purpose of these site inspections was to obtain consensus ratings of the asbestos-containing material's general condition, the extent of water damage, the quantity of material exposed, the degree of accessibility, the degree of friability, the level of human activity present, and the presence of an air plenum. The seven consensus ratings (Table A-1 of Appendix A) at each site were combined with information from the laboratory analysis of bulk samples of the asbestos-containing material to yield an algorithm score. Appendix A contains a general description of the asbestos exposure assessment algorithm used to calculate the score.

Consensus ratings of the seven subjective algorithm factors were obtained at each site by polling the five raters after they had recorded their independent assessment of the factors on a data sheet. A simple majority rule was invoked when there were disagreements among the five independent assessments. Appendix F contains examples of the three forms used to structure the collection of the site-specific data. The cover sheet was used to record information about the auxiliary variables, one sheet was used to record the algorithm data, and the third sheet collected assessment factor information. Each of the five raters independently completed both of the latter forms before a consensus vote on the algorithm was taken at each site. The cover sheet for each site was filled out by one of the EPA researchers; the other EPA researcher recorded the consensus data.

Data concerning several auxiliary variables were collected during each site inspection along with the data used to obtain the consensus ratings. The auxiliary variable data included measurements of room length and width and an estimate of room height; a notation of where the suspicious material was located; a characterization of the room floor (carpeted, tile, wood); and information about the frequency of sweeping, wet mopping, dry mopping, and vacuuming. This auxiliary information was used in some of the statistical analyses that are discussed in Section 7.

During the 3-hour training session for the five raters, assessment factors were defined, the algorithm description was presented in detail, and slides of typical asbestos-containing materials were viewed. The discussion of the algorithm was led by two individuals employed by the U.S. EPA who had previous experience using the algorithm in several situations. The EPA perspective was supplemented by that of two individuals employed by the school district who had previous experience inspecting school buildings for asbestos-containing materials. Another perspective was supplied by a researcher under contract to EPA who had previous experience analyzing algorithm data. Thus, all of the raters used in the study were familiar with the asbestos-in-schools problem, though they had had different levels of experience using the algorithm in the field.

A caveat which is pertinent to the optimal classification analysis (see Section 7) is that the air plenum data collected in this study should be viewed as airstream data. No air plenums were present in any of the 48 asbestos-containing material sites. Rather, the asbestos-containing material was located in an airstream from an air conditioning/heating unit at 23 sites. The direction of the airstream was ascertained by noting whether or not the ceiling was blackened in a characteristic pattern.

SECTION 6

SAMPLE ANALYSIS

Two types of chemical analyses were performed: transmission electron microscopy (TEM) for air samples and polarized light microscopy (PLM) for bulk samples. A total of 125 filters were analyzed by Battelle Columbus Laboratories (BCL) using TEM techniques. Of those, 116 were air samples collected at the 25 schools: 54 were indoor samples (from classrooms or other student activity areas); 31 were indoor control samples (from areas with presumably no asbestos material); 31 were outdoor ambient samples; and 9 were field blanks (filters). Quality assurance analysis of air samples was performed by the IIT Research Institute (IITRI). Midwest Research Institute (MRI) analyzed 192 bulk samples using PLM techniques. The quality assurance analysis of bulk samples was done by the Colorado School of Mines Research Institute (CSMRI).

I. AIR SAMPLES

Sample preparation and microscopic examination of the air samples were carried out according to the Analytical Protocol for Air Samples (Appendix E) established at the beginning of the program. This protocol is based on the U.S. EPA Provisional Methodology Manual (USEPA 1978). Tables 2 and 3 summarize the analytical results of chrysotile and amphibole, respectively, that were obtained from the 126 samples* collected by the field sampling team. In approximately one-half the number of schools, the air level of asbestos fibers at the control site was greater than at least one of the air levels at the asbestos-containing material sites. This phenomenon is discussed in Section 7.II.B. Fibers counted, fibers on filter, mass on filter, and volume of air sampled for the individual samples are given in Table 4.

A. Method of Analysis

The samples were logged in and randomly numbered so that the analyst would not know sample sites or relative locations of the samples. Four analysts performed the analyses on two transmission electron microscopes. A senior analyst was always available for consultation in the event of a question about the identification of a fiber or particle. The microscopic examination of the prepared grids was carried out at a magnification of 20,000X. Each grid opening to be counted was selected randomly and then systematically scanned to cover the full opening. The fibers observed were identified as chrysotile, amphibole, or other.

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* One field blank was lost; therefore, only 125 samples are given in the table

Table 2. Results of Analysis of Airborne Asbestos Fibers Collected by Filtration and Analyzed by Transmission Electron Microscopy: Chrysotile Concentration in ng/m^3

School no.	Week	Outdoor ambient	Indoor control	Site			
				1	2	3	4
1	1	0.4	69.3	28.4	8.95	108	NA*
2	1	4.10	3	11.6	73	422	32.3
	2	1.30	2.6	NA	NA	NA	61.2
	3	8.88	< 0.002	NA	NA	NA	6.8
3	1	2.7	166	NA	38.2	105	332
	2	17.6	14.6	NA	NA	27.5	NA
	3	< 0.002	45.5	11.0	NA	6.17	NA
4	1	0.02	1.4	9.66	NA	NA	NA
5	1	1.44	16.9	23.6	NA	NA	NA
6	1	0.36	43.9	37	82.8	43.0	NA
7	1	0.1	5.01	68.0	92.7	93.3	NA
8	1	0.3	362	0.1	NA	NA	NA
9	1	0.50	0.1	1	NA	NA	NA
10	1	0.55	72.9	10	NA	NA	NA
	2	10.8	50.3	0.76	NA	NA	NA
	3	1.1	73.4	1.5	NA	NA	NA
11	1	0.9	51.0	11.2	NA	NA	NA
12[a]	1	0.6	NA	0.04	< 0.002	NA	NA
	2	NA	0.50	NA	NA	NA	NA
13[a]	1	0.83	NA	18.7	55.8	NA	NA
	2	NA	NA	NA	NA	NA	NA
	3	NA	< 0.002	NA	NA	89.0	NA
14[a]	1	0.77	49.8	NA	150	89	NA
	2	NA	NA	NA	NA	NA	NA
	3	NA	NA	77.6	NA	NA	NA
15	1	3.5	21.8	69.3	NA	NA	NA
16	1	2.5	69.3	425	NA	NA	NA
17	1	40.6	4.4	149	NA	NA	NA

(continued)

Table 2 (continued)

School no.	Week	Outdoor ambient	Indoor control	Site			
				1	2	3	4
18	1	0.57	46.8	7.93	NA	NA	NA
19	1	0.90	0.5	644	NA	NA	NA
20	1	0.35	288	420	566	NA	NA
21	1	0.63	19	153	484	NA	NA
22	1	1.1	0.2	312	69.6	NA	NA
23	1	2.84	2.2	196	NA	NA	NA
24	1	0.38	25.2	77.8	11	NA	NA
25[a]	1	1.3	116	8.58	NA	245	NA
	2	NA	NA	NA	4.3	NA	NA

a Some samples were collected for too short a period or an unknown length of time due to filters being vandalized, equipment stolen, equipment failures, power interruptions, and field crew error. Repeat sampling or recycling of questionable sites was done on a priority basis. In some cases, recycling had to be done during another week. Therefore, the control and site samples were not taken during the same week.

Note: The concentrations of nine field blanks were 0.30, 1.00, 0.00, 1.00, 0.60, 0.00, 0.00, 0.60, and 0.00 ng/m^3.

* NA = not applicable (no sample taken).

Table 3. Results of Analysis of Airborne Asbestos Fibers Collected by Filtration and Analyzed by Transmission Electron Microscopy: Amphibole Concentration in ng/m^3

School no.	Week	Outdoor ambient	Indoor control	Site 1	Site 2	Site 3	Site 4
1	1	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	NA*
2	1	< 0.002	2	< 0.002	< 0.002	93	< 0.002
	2	< 0.002	0.1	NA	NA	NA	13
	3	< 0.002	< 0.002	NA	NA	NA	< 0.002
3	1	3	24	NA	< 0.002	4	6
	2	2	4	NA	NA	< 0.002	NA
	3	< 0.002	< 0.002	< 0.002	NA	< 0.002	NA
4	1	< 0.002	< 0.002	< 0.002	NA	NA	NA
5	1	2	3	< 0.002	NA	NA	NA
6	1	0.5	< 0.002	< 0.002	< 0.002	< 0.002	NA
7	1	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	NA
8	1	< 0.002	79	< 0.002	NA	NA	NA
9	1	< 0.002	< 0.002	< 0.002	NA	NA	NA
10	1	< 0.002	42	1	NA	NA	NA
	2	< 0.002	5	< 0.002	NA	NA	NA
	3	< 0.002	< 0.002	< 0.002	NA	NA	NA
11	1	< 0.002	< 0.002	< 0.002	NA	NA	NA
12[a]	1	0.6	NA	< 0.002	< 0.002	NA	NA
	2	NA	< 0.002	NA	NA	NA	NA
13[a]	1	< 0.002	NA	< 0.002	< 0.002	NA	NA
	2	NA	NA	NA	NA	NA	NA
	3	NA	< 0.002	NA	NA	< 0.002	NA
14[a]	1	0.11	< 0.002	NA	< 0.002	< 0.002	NA
	2	NA	NA	NA	NA	NA	NA
	3	NA	NA	< 0.002	NA	NA	NA
15	1	0.6	3	< 0.002	NA	NA	NA
16	1	< 0.002	0.002	52	NA	NA	NA
17	1	< 0.002	0.2	3	NA	NA	NA

(continued)

Table 3 (continued)

School no.	Week	Outdoor ambient	Indoor control	Site			
				1	2	3	4
18	1	< 0.002	9	5	NA	NA	NA
19	1	2	0.5	< 0.002	NA	NA	NA
20	1	< 0.002	< 0.002	< 0.002	< 0.002	NA	NA
21	1	< 0.002	83	< 0.002	5	NA	NA
22	1	< 0.002	< 0.002	< 0.002	< 0.002	NA	NA
23	1	< 0.002	< 0.002	< 0.002	NA	NA	NA
24	1	4	1	13	2	NA	NA
25[a]	1	< 0.002	< 0.002	< 0.002	NA	< 0.002	NA
	2	NA	NA	NA	< 0.002	NA	NA

a Some samples were collected for too short a period or an unknown length of time due to filters being vandalized, equipment stolen, equipment failures, power interruptions, and field crew error. Repeat sampling or recycling of questionable sites was done on a priority basis. In some cases, recycling had to be done during another week. Therefore, the control and site samples were not taken during the same week.

Note: The concentration of each of the nine field blanks was 0.00.

* NA = not applicable (no sample taken).

Table 4. Fundamental Data Obtained from the Analysis of the Airborne Asbestos Fiber Collected by Filtration and Analyzed by Transmission Electron Microscopy

			Chrysotile			Amphibole			
Sample no.	School[a]	Site[b]	No. of fibers counted	Estimate of number of fibers on filter	Mass on filter (g)	No. of fibers counted	Estimate of number of fibers on filter	Mass on filter (g)	Air volume sampled (m^3)
1	20	1	941	1.18×10^{9}	4.02×10^{-6}	0	0	0	9.58
2	20	IC	405	5.08×10^{8}	3.03×10^{-6}	0	0	0	10.55
3	20	OA	16	1.00×10^{6}	3.50×10^{-9}	0	0	0	9.98
4	20	2	724	9.09×10^{8}	5.31×10^{-6}	0	0	0	9.38
5	2	4(1)	122	3.83×10^{7}	3.32×10^{-7}	0	0	0	10.27
6	2	1(1)	117	2.46×10^{7}	1.20×10^{-7}	0	0	0	10.35
7	2	IC(1)	71	4.50×10^{6}	2.90×10^{-8}	3	2.00×10^{5}	2.00×10^{-8}	9.75
8	2	2(1)	164	1.03×10^{8}	7.51×10^{-7}	0	0	0	10.29
9	2	3(1)	419	2.63×10^{8}	4.04×10^{-6}	3	2.00×10^{6}	9.00×10^{-7}	9.56
10	2	OA(1)	72	4.50×10^{6}	3.80×10^{-8}	0	0	0	9.29
11	11	1	125	1.96×10^{7}	1.17×10^{-7}	0	0	0	10.40
12	11	OA	9	1.00×10^{6}	9.00×10^{-9}	0	0	0	10.71
13	11	IC	107	6.72×10^{7}	5.11×10^{-7}	0	0	0	10.01
14	c	c	1	6.00×10^{4}	6.00×10^{-11}	0	0	0	c
15	18	OA	24	7.50×10^{5}	5.40×10^{-9}	0	0	0	9.46
16	18	IC	158	4.96×10^{7}	4.58×10^{-7}	6	2.00×10^{6}	8.00×10^{-8}	9.77
17	18	1	111	1.16×10^{7}	7.73×10^{-8}	2	2.00×10^{5}	5.00×10^{-8}	9.75
18	c	c	3	2.00×10^{5}	1.00×10^{-9}	0	0	0	c
19	14	1	120	7.54×10^{7}	2.69×10^{-7}	0	0	0	3.47
20	7	3	238	2.99×10^{8}	1.01×10^{-6}	0	0	0	10.14
21	7	OA	1	6.00×10^{4}	1.00×10^{-9}	0	0	0	10.45
22	2	IC(2)	81	5.10×10^{6}	2.80×10^{-8}	1	6.00×10^{4}	1.00×10^{-9}	10.75
23	2	4(2)	201	1.26×10^{8}	6.38×10^{-7}	8	5.00×10^{6}	1.00×10^{-7}	10.44
24	2	OA(2)	35	2.20×10^{6}	1.20×10^{-8}	0	0	0	9.66
25	8	OA	4	2.00×10^{5}	3.00×10^{-9}	0	0	0	9.83
26	8	1	3	2.00×10^{5}	1.00×10^{-9}	0	0	0	10.77
27	8	IC	632	7.94×10^{8}	3.76×10^{-6}	26	3.30×10^{7}	7.80×10^{-7}	10.37

(continued)

Table 4 (continued)

Sample no.	School[a]	Site[b]	Chrysotile: No. of fibers counted	Chrysotile: Estimate of number of fibers on filter	Chrysotile: Mass on filter (g)	Amphibole: No. of fibers counted	Amphibole: Estimate of number of fibers on filter	Amphibole: Mass on filter (g)	Air volume sampled (m^3)
28	c	c	0	0	0	0	0	0	c
29	14	IC	114	7.16×10^{7}	4.52×10^{-7}	0	0	0	9.08
30	14	2	99	1.20×10^{8}	7.80×10^{-7}	0	0	0	9.77
31	14	3	184	2.31×10^{8}	1.88×10^{-6}	0	0	0	9.18
32	14	OA	76	1.40×10^{6}	6.40×10^{-9}	1	2.00×10^{4}	9.00×10^{-9}	8.36
33	25	1	114	1.43×10^{7}	8.30×10^{-8}	0	0	0	9.67
34	25	IC	331	2.08×10^{8}	1.14×10^{-6}	0	0	0	9.88
35	25	3	343	4.31×10^{8}	2.32×10^{-6}	0	0	0	9.48
36	25	OA	13	8.20×10^{5}	5.20×10^{-9}	0	0	0	4.11
37	2	I(3)	0	0	-	0	0	0	9.52
38	2	4(3)	99	7.80×10^{6}	6.90×10^{-8}	0	0	0	10.23
39	2	OA(3)	114	1.79×10^{7}	9.03×10^{-8}	0	0	0	10.18
40	4	1	113	1.42×10^{7}	9.14×10^{-8}	0	0	0	9.46
41	4	IC	64	4.00×10^{6}	1.50×10^{-8}	0	0	0	10.95
42	4	OA	1	6.00×10^{4}	2.00×10^{-10}	0	0	0	9.23
43	19	OA	22	1.40×10^{6}	9.10×10^{-9}	7	4.00×10^{5}	2.00×10^{-8}	10.04
44	19	IC	8	1.00×10^{6}	5.00×10^{-9}	1	1.00×10^{5}	5.00×10^{-9}	10.61
45	19	1	789	9.91×10^{8}	6.32×10^{-6}	0	0	0	9.82
46	10	IC(1)	204	1.28×10^{8}	8.30×10^{-7}	7	4.00×10^{6}	5.20×10^{-7}	11.39
47	24	OA	16	5.00×10^{5}	4.10×10^{-9}	1	3.00×10^{4}	5.00×10^{-8}	10.78
48	15	OA	59	3.70×10^{6}	3.30×10^{-8}	2	1.00×10^{5}	5.00×10^{-9}	9.42
49	15	1	144	9.04×10^{7}	6.47×10^{-7}	0	0	0	9.33
50	15	IC	123	2.58×10^{7}	2.04×10^{-7}	2	4.00×10^{5}	3.00×10^{-8}	9.35
51	12	OA	8	5.00×10^{5}	6.00×10^{-9}	1	6.00×10^{4}	5.00×10^{-9}	8.84
52	12	1	1	6.00×10^{4}	3.00×10^{-10}	0	0	0	8.25
53	12	2	0	0	-	0	0	0	8.80
54	3	1(3)	122	2.56×10^{7}	9.80×10^{-8}	0	0	0	8.94
55	3	OA(3)	0	0	-	0	0	0	9.80

(continued)

Table 4 (continued)

Sample no.	School[a]	Site[b]	Chrysotile: No. of fibers counted	Chrysotile: Estimate of number of fibers on filter	Chrysotile: Mass on filter (g)	Amphibole: No. of fibers counted	Amphibole: Estimate of number of fibers on filter	Amphibole: Mass on filter (g)	Air volume sampled (m^3)
56	3	3(3)	102	1.28×10^{7}	6.26×10^{-8}	0	0	0	10.14
57	3	IC(3)	103	6.47×10^{7}	4.67×10^{-7}	0	0	0	10.28
58	1	IC	106	4.45×10^{7}	5.62×10^{-7}	0	0	0	8.11
59	1	2	117	1.84×10^{7}	8.60×10^{-8}	0	0	0	9.62
60	1	OA	3	2.00×10^{5}	3.00×10^{-9}	0	0	0	7.56
61	12	IC	13	8.20×10^{5}	3.00×10^{-9}	0	0	0	6.07
62	6	IC	128	8.04×10^{7}	3.11×10^{-7}	0	0	0	7.09
63	6	1	95	6.00×10^{7}	3.30×10^{-7}	0	0	0	8.84
64	6	2	132	1.66×10^{8}	7.42×10^{-7}	0	0	0	8.96
65	6	3	121	7.60×10^{7}	3.38×10^{-7}	0	0	0	7.86
66	6	OA	11	6.90×10^{5}	3.00×10^{-9}	1	6.00×10^{4}	4.00×10^{-9}	8.15
67	10	OA(1)	17	1.10×10^{6}	6.60×10^{-9}	0	0	0	11.87
68	3	2(1)	163	5.12×10^{7}	3.84×10^{-7}	0	0	0	10.07
69	3	IC(1)	575	3.61×10^{8}	1.73×10^{-6}	6	4.00×10^{6}	3.00×10^{-7}	10.39
70	3	3(1)	472	2.96×10^{8}	1.06×10^{-6}	2	1.00×10^{6}	4.00×10^{-8}	10.06
71	24	(2)	85	1.10×10^{7}	1.30×10^{-7}	2	3.00×10^{5}	3.00×10^{-8}	10.98
72	21	OA	10	6.30×10^{5}	6.20×10^{-9}	0	0	0	9.73
73	21	1	148	1.86×10^{8}	1.48×10^{-6}	0	0	0	9.68
74	10	IC(2)	180	1.13×10^{8}	5.15×10^{-7}	2	1.00×10^{6}	5.00×10^{-8}	10.24
75	10	1(2)	26	1.60×10^{6}	7.60×10^{-9}	0	0	0	9.93
76	10	OA(2)	101	1.59×10^{7}	1.10×10^{-7}	0	0	0	10.18
77	17	IC	54	3.40×10^{6}	4.10×10^{-8}	2	1.00×10^{5}	2.00×10^{-9}	9.32
78	17	1	651	4.09×10^{8}	1.37×10^{-6}	3	2.00×10^{6}	2.00×10^{-8}	9.15
79	17	OA	102	6.41×10^{7}	3.90×10^{-7}	0	0	0	9.59
80	c	c	3	2.00×10^{5}	8.00×10^{-10}	0	0	0	c
81	5	1	125	3.93×10^{7}	2.39×10^{-7}	0	0	0	10.15
82	5	IC	149	4.68×10^{7}	1.69×10^{-7}	1	3.00×10^{5}	2.00×10^{-8}	9.97
83	c	c	1	1.00×10^{5}	1.00×10^{-10}	0	0	0	c

(continued)

Table 4 (continued)

Sample no.	School[a]	Site[b]	Chrysotile: No. of fibers counted	Chrysotile: Estimate of number of fibers on filter	Chrysotile: Mass on filter (g)	Amphibole: No. of fibers counted	Amphibole: Estimate of number of fibers on filter	Amphibole: Mass on filter (g)	Air volume sampled (m^3)
84	23	OA	181	1.89×10^{7}	2.31×10^{-8}	0	0	0	8.15
85	23	1	805	5.06×10^{8}	1.83×10^{-6}	0	0	0	9.34
86	23	IC	78	4.90×10^{6}	1.70×10^{-8}	0	0	0	7.69
87	c	c	0	0	-	0	0	0	c
88	16	OA	22	2.80×10^{6}	2.30×10^{-8}	0	0	0	8.92
89	16	1	659	8.30×10^{8}	3.56×10^{-6}	9	1.00×10^{7}	4.00×10^{-7}	8.37
90	16	IC	246	1.54×10^{8}	5.65×10^{-7}	0	0	0	8.16
91	c	c	0	0	-	0	0	0	c
92	9	IC	4	3.00×10^{5}	1.00×10^{-9}	0	0	0	10.54
93	9	1	18	1.10×10^{6}	9.80×10^{-9}	0	0	0	9.69
94	9	OA	15	9.40×10^{5}	4.70×10^{-9}	0	0	0	9.36
95	22	1	338	4.25×10^{8}	3.10×10^{-6}	0	0	0	9.92
96	22	2	270	1.70×10^{8}	6.46×10^{-7}	0	0	0	9.28
97	22	OA	22	1.40×10^{6}	1.10×10^{-8}	0	0	0	9.61
98	22	IC	3	2.00×10^{5}	2.00×10^{-9}	0	0	0	10.47
99	c	c	2	1.00×10^{5}	1.00×10^{-10}	0	0	0	c
100	7	IC	101	6.34×10^{6}	4.61×10^{-8}	0	0	0	9.21
101	7	1	210	1.32×10^{8}	6.55×10^{-7}	0	0	0	9.63
102	7	2	274	1.72×10^{8}	6.72×10^{-7}	0	0	0	7.25
103	13	3	352	2.21×10^{8}	5.38×10^{-7}	0	0	0	6.05
104	10	1(1)	99	1.20×10^{7}	1.20×10^{-7}	1	1.00×10^{5}	1.00×10^{-8}	11.27
105	3	4(1)	509	6.39×10^{8}	3.34×10^{-6}	2	3.00×10^{6}	6.00×10^{-8}	10.06
106	3	OA(1)	16	2.00×10^{6}	2.60×10^{-8}	4	5.00×10^{5}	3.00×10^{-8}	9.73
107	24	IC	104	3.27×10^{7}	2.81×10^{-7}	1	3.00×10^{5}	1.00×10^{-8}	11.14
108	24	1	113	7.10×10^{7}	8.22×10^{-7}	1	6.00×10^{5}	1.00×10^{-7}	10.57
109	21	IC	119	1.80×10^{7}	1.75×10^{-7}	3	5.00×10^{5}	8.00×10^{-7}	9.24
110	21	2	398	5.00×10^{8}	4.43×10^{-6}	1	1.00×10^{6}	4.00×10^{-8}	9.14
111	d	d	d	d	d	d	d	d	d
112	3	IC(2)	137	4.30×10^{7}	1.45×10^{-7}	1	3.00×10^{5}	4.00×10^{-8}	9.96

(continued)

Table 4 (continued)

Sample no.	School[a]	Site[b]	Chrysotile: No. of fibers counted	Chrysotile: Estimate of number of fibers on filter	Chrysotile: Mass on filter (g)	Amphibole: No. of fibers counted	Amphibole: Estimate of number of fibers on filter	Amphibole: Mass on filter (g)	Air volume sampled (m^3)
113	3	3(2)	112	7.03×10^{7}	2.98×10^{-7}	0	0	0	10.80
114	3	OA(2)	105	1.65×10^{7}	1.92×10^{-7}	3	5.00×10^{5}	2.00×10^{-8}	10.87
115	13	OA	35	2.20×10^{6}	8.50×10^{-9}	0	0	0	10.14
116	13	2	272	1.71×10^{8}	5.35×10^{-7}	0	0	0	9.59
117	13	1	100	6.28×10^{7}	1.97×10^{-7}	0	0	0	10.55
118	5	OA	14	1.80×10^{6}	1.60×10^{-8}	3	4.00×10^{5}	2.00×10^{-8}	11.02
119	10	IC(3)	165	1.04×10^{8}	7.25×10^{-7}	0	0	0	9.86
120	10	1(3)	53	3.33×10^{6}	1.40×10^{-8}	0	0	0	8.84
121	10	OA(3)	16	1.00×10^{9}	8.90×10^{-9}	0	0	0	8.16
122	1	3	374	2.35×10^{8}	1.03×10^{-6}	0	0	0	9.49
123	1	1	133	2.09×10^{7}	1.36×10^{-7}	0	0	0	4.79
124	25	2	62	3.90×10^{6}	1.70×10^{-8}	0	0	0	3.83
125	c	c	0	0	-	0	0	0	c
126	13	IC	0	0	0	0	0	0	3.12

a The school where the sample was taken. See Tables 2 and 3.

b The site at the school where the sample was taken. The number in parentheses identifies the week in which the sample was taken. See Tables 2 and 3. IC = indoor control and OA = outdoor ambient.

c Filter blanks. No air sampled.

d Sample No. 111 was a blank filter that was lost. Therefore, there were no data.

The length and width of the chrysotile and amphibole fibers were recorded. The fiber length was measured using the number of concentric circles on the viewing screen that the fiber crossed (each circle segment was 0.25 µm at 20,000X). The width was measured in millimeters on the viewing screen. The fiber was aligned with the millimeter scale on the side of the viewing screen (1 mm = 0.05 µm at 20,000X). The volume of the fiber was then computed assuming the fiber to be a right circular cylinder. The mass of the fiber was calculated using a density of 2.6 g/cm^3 for the chrysotile and 3.0 g/cm^3 for the amphibole. Appropriate filter area factors and dilution factors were used to extrapolate from the fibers actually counted and measured to the total number of fibers per filter and total nanograms of asbestos per filter.

The detection limit for this type analysis is one fiber observed while 10 grid openings are scanned. The protocol calls for the counting of 100 fibers or 10 grid openings but never any partial grid openings. One fiber observed in 10 grid openings would correspond to 4×10^3 fibers per filter when the extrapolation is made to total filter area. If the one fiber were of average dimensions (1 µm long x 0.05 µm in diameter), the mass would be 2×10^{-11} g per filter. Since most of the air volumes per sample were approximately 10 m^3, the minimum detectable quantities would be 2×10^{-12} g/m^3 or 0.002 ng/m^3.

The quantification limit for these analyses depends upon the number of fibers observed during the TEM analysis. The number of fibers counted during TEM analysis ranges from a minimum of 1 to a maximum of 941. Thus, the number of significant figures for the results will range from 1 to 3.

The method of selecting the filter fraction to be ashed was generally the same for each sample. The large amount of debris collected on many of the filters made the low temperature ashing procedure a necessity. After ashing, the residue containing the asbestos fibers was resuspended in 100 ml of water using the ultrasonic bath to ensure that the fibers were removed from the ashing tube walls. The resuspended sample was then divided into 10-ml, 20-ml, and 70-ml aliquots, and each aliquot was filtered onto a Nuclepore filter. The three aliquots gave the analyst some flexibility in finding a suitable fiber loading for TEM examination.

B. Discussion

Initial examination of some of the filters showed debris on the prepared filter grid. The debris often necessitated using the 20-ml aliquot rather than the 70-ml aliquot. The debris apparently was composed of dust and paint chips collected at the sampling site on the sample filter. Any organic fibers or other organic debris was removed during the low temperature ashing procedure.

Fiber bundles and fiber clusters in the samples that contained large quantities of asbestos required special attention. Bundle is defined as a group of fibers bound together that makes the determination of its constituents difficult. Often it was possible to identify one end of a fiber, but it was not always possible to identify positively the constituents of the bundle. Cluster is defined as several overlapping and cross-linked individual fibers.

Fibers in a cluster that could be seen as individual fibers were counted as individual fibers, but when the individual fibers could not be distinguished, they were considered a cluster and recorded as such, but not counted. Many times the cluster formed around a paint chip. Another problem was in determining whether these bundles and clusters were evenly distributed throughout the filter or were isolated events. (The chrysotile fibers were observed to form bundles and clusters, but the amphibole fibers did not.)

The way in which bundles and clusters are handled can greatly affect the quantity of asbestos calculated for each filter. The analysis does not include the bundles and clusters in the calculation primarily because the analyst could not be sure of uniform distribution or rely on the volume calculations associated with the bundles and clusters. Table 5 lists the number of bundles and clusters for each sample. There were 82 samples that had some bundles or clusters. Fifteen of these were outdoor ambient samples and 23 were indoor control samples. The remaining 47 were asbestos-containing material site samples. The 15 outdoor ambient samples averaged 2.7 bundles/clusters per sample. If the total 31 outdoor ambient samples (16 had no bundles/clusters) taken are considered, the average is 1.3. The 23 indoor control samples averaged 7.8 bundles/clusters per sample. If the total 31 indoor control samples (8 had no bundles/clusters) taken are considered, the average is 5.7. The 47 site samples averaged 8.3 bundles/clusters per sample. If the total 54 site samples (7 had no bundles/clusters) taken are considered, the average is 7.2

Bundles and clusters have some mass; therefore, the calculations represent a minimum value for the quantity of asbestos for these samples. The samples with higher asbestos concentrations tended to have more bundles and clusters. The bundles and clusters were observed on the TEM-prepared filter and must have been deposited as such on the filter during air sampling. The ultrasonification procedure that followed the low temperature ashing tended to break up the fiber bundles and clusters. The primary purpose of sonification was to ensure the removal of fibers from the glass test tube in which the ashing took place. All samples were subjected to the same low temperature ashing and sonification procedure, done according to the protocol; therefore, the effect is assumed to be the same for each sample.

C. Quality Assurance

The transmission electron microscopy analysis was carried out by four persons trained in microscopy. A senior analyst was always available for consultation if there was a question about identification. The sample preparation was also carried out by persons who had previous experience in preparing samples for microscopic examination. Both the preparation and analysis were carried out according to the protocol contained in Appendix E.

Although this protocol is accepted and used by expert microscopists, there are factors that contribute to the possibility of having relatively large variabilities in results. These factors include agglomeration (bundles and clusters) during the ashing operation that is not included in the fiber count, since the number of fibers cannot be ascertained; the possible transfer (loss or gain) of fibers when a number of filters are processed at the same

Table 5. The Number of Chrysotile Bundles and Clusters Observed on the Filter but Not Used in the Mass Calculations

Sample no.	Chrysotile bundles/clusters	Sample no.	Chrysotile bundles/clusters
1	54	63	6
2[a]	40	68	9
4	40	71	7
5	14	72[b]	1
6	3	73	1
8	3	74[a]	10
9	6	76[b]	2
10[b]	1	77[a]	1
11	2	78	23
13[a]	12	79[b]	1
15[b]	2	81	2
16[a]	2	82[a]	2
17	3	84[b]	6
19	4	85	2
20	3	86[a]	6
21[b]	3	88[b]	5
22[a]	2	89	35
23	5	90[a]	4
27[a]	22	93	2
29[a]	5	95	5
30	1	96	7
31	12	97[b]	4
32[b]	4	100[a]	5
33	1	101	14
34[a]	15	102	22
35	8	103	14
38	4	104	4
39[b]	4	105	7
40	4	106[b]	3
41[a]	3	107[a]	9
43[b]	1	108	5
45	8	109[a]	7
46[a]	8	110	5
47[b]	2	112[a]	2
49	1	113	4
50[a]	3	114[b]	1
54	8	116	13
56	1	117	6
57[a]	1	119[a]	13
58[a]	4	120	1
59	1	122	6
62[a]	3	123	3

a Sample from an indoor control site. There were eight other indoor control samples (Nos. 7, 37, 44, 61, 69, 92, 98 and 126), but there were no bundles or clusters on these.

b Sample from an outdoor control site. There were 16 other outdoor ambient samples (Nos. 3, 12, 24, 25, 36, 42, 48, 51, 55, 60, 66, 67, 94, 115, 118 and 121), but there were no bundles or clusters on these.

time, or the loss when a single filter is processed; the effectiveness of the dispersion of fibers during the sonication process; the production of a non-uniform deposit of the fibers during the filtration operation; and the relative error in calculating the mass concentration of fibers. Further improvement of the protocol is recognized as being needed but was beyond the scope of this task.

The quality assurance aspect of the analytical part of this program is summarized in the following paragraphs. As a quality assurance measure, samples were randomly selected for analysis by IITRI. Table 6 lists the samples selected and the results obtained at IITRI and BCL.

The filters were divided at BCL, and one-half of each filter was hand-carried to IITRI; the deposited side was kept up at all times. Results for some of the samples showed large differences even though the same analytical protocol was used by both laboratories. Since it did not seem likely that there could be enough inhomogeneity of the filter deposit to produce these large differences, each laboratory reexamined the prepared grids where differences were observed. They concluded that the microscopic examinations had been correct and that the variation must have been due either to inhomogeneity in the filter deposit or to laboratory contamination during preparation of the filters for microscopic examination. BCL repeated the analysis of samples 95 and 110 starting with a new section of the original air sample filter. The results of this second analysis, shown in Table 6, indicated that there was a high concentration of chrysotile in these samples. During IITRI's reexamination of sample 98 by a qualitative comparison of a second dilution, no amphibole fibers were detected. IITRI believed that the first dilution examined was contaminated; therefore, the results of this sample should be discarded, or used with great caution.

Table 7 shows the results of duplicate and replicate analyses for chrysotile conducted at BCL. The duplicate analyses were conducted by a second analyst using the same grid preparation as was used in the original analyses. In a few cases, different aliquot preparations were analyzed. The replicate analyses were performed using two independent preparations. Figure 2 shows the relative variation* of the analysis pairs plotted against the average value of the pairs. The symbol "Z" denotes the duplicates and "A" denotes the replicates. Except for very low concentrations, the percentage relative variation does not exceed 40% and is independent of the measured asbestos concentration level. The levels of variation experienced in this study are consistent with other reports on the use of TEM for asbestos analysis (USEPA 1980f). The variation in the airborne asbestos concentration levels across sites sampled in this study far exceeds 40%. The indication is that the analytical variability is within an acceptable range and the data are appropriate for their intended use.

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* Relative variation is also known as the coefficient of variation computed as standard deviation divided by mean or $s/\bar{x}$.

Table 6. Quality Assurance Results of Transmission Electron Microscopy Analysis

Sample no.	Asbestos concentration (ng/m^3)					
	IITRI		BCL		BCL-repeat	
	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole
5	6.50	0.030	32.3	0		
10	1.40	1.60	4.10	0		
22	0.250	0	2.64	0.103		
25	0.770	0	0.306	0		
50	22.6	113	21.8	2.68		
88	0.230	32.0	2.54	0		
90	45.7	0	69.3	0		
92	0.090	0	0.103	0		
95	15.5	0	312	0	514	0
98	1.30	1,740[a]	0.214	0		
110	4.40	0	484	4.86	275	0

a In a qualitative examination of a second dilution, no amphibole fibers were observed. IITRI believes the first dilution was contaminated; therefore, this result should be discarded or be used with great caution.

Table 7. Quality Assurance Results of Duplicate Sample Analysis for Chrysotile[a]

Sample no.	Reported ng/m³	Duplicate ng/m³
Duplicates		
17	7.93	13.5
20	99.3	70.2
32	0.770	1.50
39	8.88	4.66
47	0.379	0.200
67	0.554	0.720
72	0.634	1.20
76	10.8	6.28
79	40.6	56.6
94	0.504	1.50
96	69.6	80.1
97	1.14	0.710
104	10.4	16.0
Replicates		
95	312	514
110	484	275

a Samples analyzed by two different TEM operators (same grid preparation but different areas).

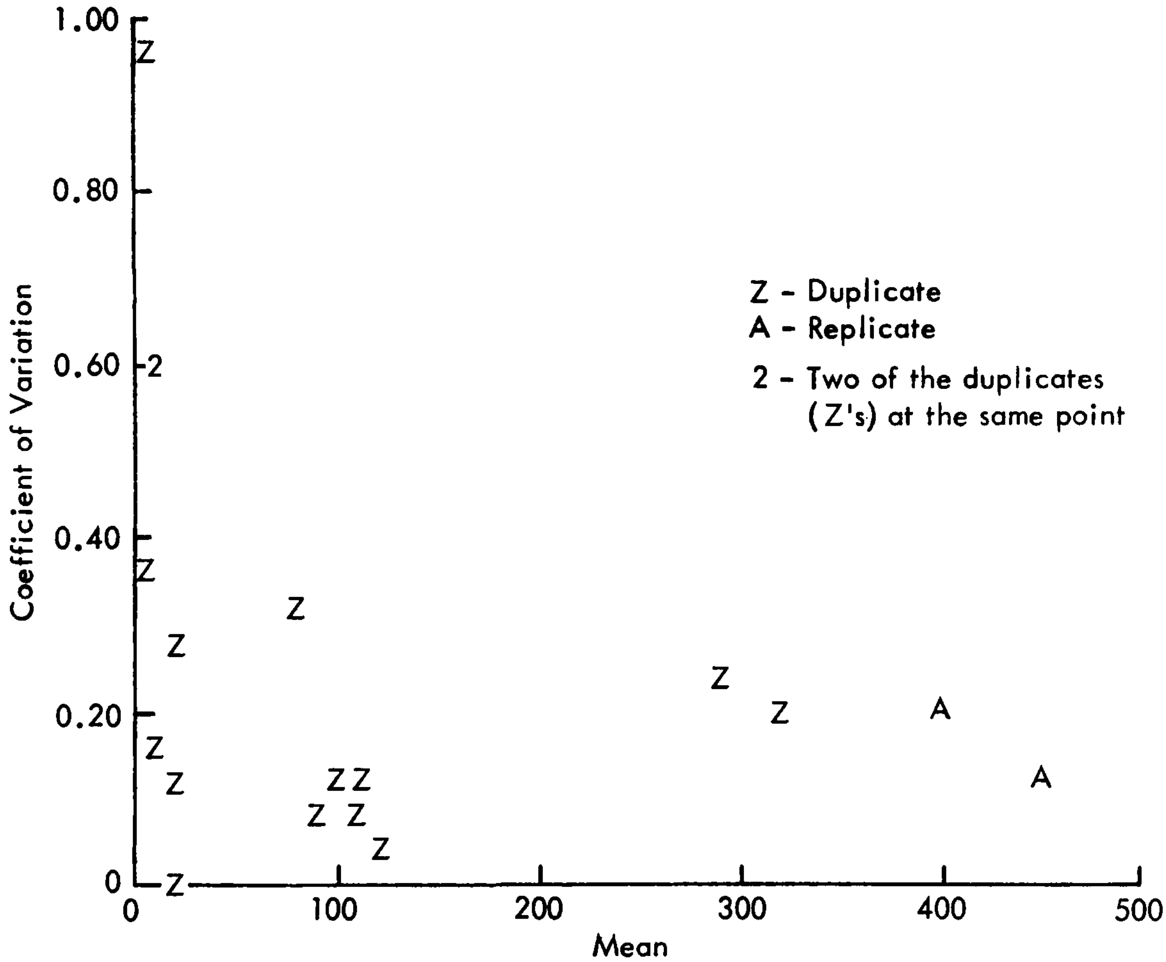


Figure 2. TEM analytical precision for airborne asbestos concentration: coefficient of variation versus mean (fibers/cc).

There was one field filter blank from each school for a total of 25. Nine of these were selected at random and analyzed. Table 8 presents BCL's results of the analysis of the nine field filter blanks. The filter blanks were taken directly from the filter box, placed in a petri filter holder, and carried to BCL along with the exposed samples. The analyst did not know which samples were field blanks; these samples were prepared and analyzed like all other samples. The low asbestos counts indicate that the laboratory or handling contamination was no greater than 1.3 ng per filter.

Table 8. Quality Assurance Results of Field Blank Analysis for Chrysotile[a]

Sample no.	ng/filter
14	0.060
18	1.0
28	0
80	0.80
83	0.12
87	0
91	0
99	0.13
125	0

a There was no amphibole detected.

Table 9 shows the results obtained from analysis of laboratory blanks. The laboratory blank was either a blank filter in an ashing tube or an empty tube placed beside each sample tube. Each sample was ashed in a test tube (the test tubes were never reused), and each sample test tube had a blank test tube placed beside it in the low temperature ashing chamber. The laboratory blank provided a continuous check on possible contamination during the preparation procedure. These results show that a few fibers were picked up by the blank during preparation, but this small amount had no effect on the quantities observed on the actual samples.

Table 9. Quality Assurance Results of Laboratory Blank Analysis for Chrysotile[a]

Blank no.	ng/filter
E 1	1
E 2	1
E 3	1
E 4	0.3
E 5	0.6
E 6	0
E 7	0.4
E 8	0.3
E 9	0.08
E 10	0.2
E 11	0.09
E 39	0.4
E 42	0.1
E 51	0.1
E 56	0.3
E 61	0.1
E 64	0.08
E 73	0
E 83	0.2
E 89	0.1
E 100	0

a Blank filters added to the analysis scheme for a check on laboratory contamination.

II. BULK SAMPLES

Three bulk samples and one duplicate were collected at each of the 48 air sampling sites for a total of 192 bulk samples. Twenty-four of the duplicates were randomly selected for quality assurance analysis by Colorado School of Mines Research Institute (CSMRI). The remaining duplicates, as well as the balance of the 192 samples, were analyzed at Midwest Research Institute (MRI).

A. Method of Analysis

The samples were analyzed by PLM according to the protocol given in Appendix D. For the analysis MRI used a stereo zoom microscope capable of 8X to 40X magnification and equipped with a built-in illuminator and external illuminator for oblique illumination, and a polarizing microscope capable of 100X magnification and equipped with an external illuminator and dispersion staining objective.

Each bulk sample was emptied onto a clean weighing paper, and the entire sample was examined as a whole through the stereomicroscope for layering, homogeneity, and the presence of fibrous material. Identification of macro-size nonfibrous components was usually possible at this point.

Four or more subsamples of the bulk sample were selected using the stereomicroscope. They were then mounted onto a clean microscope slide in the appropriate index of refraction liquids for examination through the polarizing microscope.

The PLM procedure consisted of observing the characteristics of the subsample components with transmitted polarized light, crossed polars, slightly uncrossed polars, crossed polars plus the first-order red compensator, and the central stop dispersion staining objective. The observations obtained using the various techniques were used to identify the fibrous and some of the nonfibrous components on the basis of morphology, signs of elongation, and refractive index/dispersion staining colors.

Quantitation of the asbestos was achieved by stereomicroscopic observation of the entire bulk sample through the stereomicroscope and PLM examination of the subsamples. The volume percentages of the various components were estimated in relationship to the whole sample.

B. Discussion

The results of all the analyses of bulk samples, including the quality assurance analyses, are presented in Table 10. These results are grouped by location and by site. Chrysotile asbestos was found in all the bulk samples, and traces of amosite were found in three samples (539D, 641D, 583). The majority of samples contained 1 to 50% asbestos (by volume), which is one of the three ranges the algorithm considers: less than 1%, 1 to 50%, and greater than 50%.

A number of the samples presented analytical difficulties. Binders present in these samples hindered the visibility of the fibers when using the polarizing microscope. In an attempt to eliminate this hindrance, the samples were treated with hexametaphosphate to remove the binders. This did not work well, possibly because of the small size of the fibers.

Five types of decorative insulation materials were seen in the study of samples: a perlite-based material; a mixed perlite-vermiculite-based material containing significant amounts of cellulose fiber; a glass-wool-based material; and a double-layered insulation consisting of a vermiculite-based layer and perlite-based layer. The perlite layer was the exposed surface at the sampling sites.

A significant number of the bulk samples were double-layered, both layers containing chrysotile asbestos. MRI examined and reported the two layers of these materials separately. The outer layer data were used in the statistical analysis of results.

Table 10. Results of Polarized Light Microscopic Analysis of Bulk Samples for Volume of Chrysotile, Size of Fibers, Coating on Fibers, Releasability Rating of Material, and Nonasbestos Components

School no.	Site	Bulk sample no.[a]	Analysis lab[b]	Chrysotile volume %	Fiber size[c] (by %) F	M	L	Coat[d]	R.R[e]	Nonasbestos components volume %
1	1	585[f]	M	20	50	50	0		6	Perlite 60, binder 19
		585[f]	M	22						Vermiculite 60, binder 15
		510[f]	M	20	25	75	0		3	Perlite/binder 75-80
		510[f]	M	20						Vermiculite/binder 75-80
		510 QA	M	10	20	70	10			Vermiculite 60
		634 D	M	8	40	50	10		7	Perlite/binder 85
		533 D	C	34						Perlite 52, gypsum 8
1	2	691[f]	M	25	70	30	0		6	Perlite 75
		691[f]	M	15						Vermiculite 85, glass 2
		613	M	33	75	10	15		7	Perlite/binder 65
		534 D[f]	M	28	70	20	5		5	Perlite/plaster 65
		534 D[f]	M	25						Vermiculite/binder 65, cellulose 10
		678 D[f]	M	5	90	10	0		5	Perlite 95
		678 D[f]	M	5						Vermiculite 90
1	3	504[f]	M	30	90	10	0		8	Perlite/binder 70
		504[f]	M	20				F		Vermiculite 60, binder 20
		517[f]	M	30	100	0	0		8	Perlite/binder 70
		517[f]	M	28						Vermiculite 60-70, binder 10-15
		674 D[f]	M	10	50	50	0		5	Perlite/binder 90
		674 D[f]	M	15						Vermiculite 60, binder 20
		674 QA	M	10	30	30	40			Vermiculite 60, perlite 25, binder 5
		658 D[g]	C	10						Perlite 50, vermiculite 20, gypsum 18

(continued)

Table 10 (continued)

School no.	Site	Bulk sample no.[a]	Analysis lab[b]	Chrysotile volume %	Fiber size[c] (by %) F	M	L	Coat[d]	R.R[e]	Nonasbestos components volume %
2	1	672	M	5	100	0	0		4	Perlite/binder 95
		611[f]	M	8	100	0	0		3	Perlite/binder 90
		611[f]	M	15						Vermiculite 50, binder 25
		611 QA	M	5	20	70	10			Vermiculite 75, perlite 10, binder 10
		655 D	M	8	20	70	10		6	Vermiculite 85, binder 5
		646 D[f]	M	10	100	0	0		3	Perlite/binder 90
		646 D[f]	M	18						Vermiculite 55-60, binder 20
2	2	575	M	35	95	5	0		8	Perlite/binder 65
		548	M	23	29	70	1		7	Perlite/binder 75
		622 D	M	25	60	40	0	F	6	Vermiculite/binder 75
		594 D	C	15						Vermiculite 65, binder 10, gypsum 5, carbonate 5
2	3	527	M	12	40	50	10		8	Perlite/binder 85-90
		680	M	10	90	10	0		6	Perlite 70, binder 20
		557 D	M	1	100	0	0		9	Perlite/binder 20, vermiculite 60, cellulose 20
		568 D[f]	M	5	90	10	0		7	Perlite 75, binder 15-20
		568 D[f]	M	5						Vermiculite 50, perlite 20, cellulose 20
2	4	645	M	10					3	Vermiculite 40, cellulose perlite 15, binder 10
		649	M	1					8	Vermiculite 50, cellulose perlite 15, binder 5-10
		532 D	M	10	5	95	0		7	Vermiculite 30, cellulose perlite 20, binder 15
		502 D	C	2						Vermiculite 33, perlite 55

(continued)

Table 10 (continued)

School no.	Site	Bulk sample no.[a]	Analysis lab[b]	Chrysotile volume %	Fiber size[c] (by %)			Coat[d]	R.R[e]	Nonasbestos components volume %
					F	M	L			
3	1	636	M	6	100	0	0		4	Perlite 60, binder 32
		523	M	12	99	1	0		6	Perlite 68, binder 20
		508 D	C	8						Perlite 37, carbonate 53
		540 D	M	8	100	0	0		5	Perlite 82, binder 10
		540 QA	M	10	60	40	0			Perlite 70, carbonate 20
3	2	620	M	5	95	5	0	F	4	Perlite 80, binder 15
		623	M	8	95	5	0	F	4	Perlite 90, binder 2
		643 D	M	5	100	0	0		4	Perlite 70, binder 25
		629 D	C	12						Perlite 54, carbonate 31
3	3	673	M	5	100	0	0		5	Perlite 70, binder 25
		656	M	4	100	0	0		5	Perlite 70, binder 26
		615 D	M	3	100	0	0		4	Perlite 80, binder 17
		525 D	M	8	100	0	0		4	Perlite 90
3	4	552	M	6	100	0	0		4	Perlite 80, binder 14
		633	M	8	100	0	0		6	Perlite 80, binder 10
		698 D	M	6	100	0	0		6	Perlite 80, binder 5
		581 D	C	5						Perlite 48, carbonate 44
4	1	521	M	5	100	0	0	F	6	Perlite 70, binder 25
		647	M	3	99	1	0		4	Perlite 70, binder 27
		697 D	M	5	100	0	0		5	Perlite 70, binder 23
		562 D	M	15	100	0	0		3	Perlite 70, binder 15
5	1	576	M	60	0	10	90		4	Glass wool/binder 40
		640	M	60	0	10	90		4	Glass wool 35, binder 5
		640 QA	M	50	20	40	40			Glass wool 50
		592 D	M	20	0	20	80		3	Glass wool 75, binder 5
		692 D	M	40	0	20	80		2	Glass wool 60

(continued)

Table 10 (continued)

School no.	Site	Bulk sample no.[a]	Analysis lab[b]	Chrysotile volume %	Fiber size[c] (by %) F	M	L	Coat[d]	R.R[e]	Nonasbestos components volume %
6	1	682	M	10	45	50	5		8	Perlite/binder 90
		604	M	10	90	5	5		8	Perlite/binder 90
		577 D	M	10	10	70	20		8	Perlite/binder 90
		537 D	M	25	10	30	60		6	Perlite/binder 70
6	2	588	M	20	10	60	30		9	Perlite/binder 80
		665	M	15	5	20	75		7	Perlite/binder 85
		664 D	M	10	5	45	50		8	Perlite/binder 90
		570 D	C	40						Perlite 45, cellulose 10, binder 3
6	3	598	M	15	25	50	25	F	9	Perlite/binder 80-85
		650	M	15	20	50	30		8	Perlite/binder 85
		650 QA	M	30	50	40	10			Perlite 60, binder 10
		639 D	M	25	10	40	50		8	Perlite/binder 75
		551 D	M	22	25	50	25		8	Perlite/binder 78
7	1	580	M	5	100	0	0		4	Perlite 70, binder 25
		632	M	5	100	0	0		5	Perlite 75, binder 20
		681 D	M	8	90	10	0		3	Perlite 65, binder 27
		545 D	C	2						Perlite 59, carbonate 31, gypsum 3
7	2	599	M	12	100	0	0		4	Perlite 70, binder 18
		696	M	12	100	0	0		5	Perlite 70, binder 18
		669 D	M	8	100	0	0		6	Perlite 70, binder 20
		542 D	C	7						Perlite 43, carbonate 45
7	3	612	M	8	90	10	0	F,S	3	Vermiculite 82, binder 10
		612 QA	M	7	60	40	0			Vermiculite 85, binder/clay/gypsum 8

(continued)

Table 10 (continued)

School no.	Site	Bulk sample no.[a]	Analysis lab[b]	Chrysotile volume %	Fiber size[c] (by %) F	M	L	Coat[d]	R.R[e]	Nonasbestos components volume %
		660	M	14	100	0	0	S	6	Vermiculite 76, binder 10
		677 D	M	6	100	0	0		5	Perlite 89, binder 5
		657 D	C	4						Perlite 52, carbonate 45
8	1	541	M	70	10	20	70		2	Glass wool 30
		648	M	60	0	10	90		5	Glass wool 30, plaster/ gypsum 10
		554 D	M	66	0	25	75		2	Glass wool 33
		662 D	M	50	0	10	90		4	Glass wool 50
9	1	621	M	60	0	5	95		5	Glass wool 35, surface coat 5
		690	M	50	0	20	80		3	Glass wool 50
		603 D	M	45	0	10	90		2	Glass wool 50, binder 5
		694 D	M	40	0	10	90		3	Glass wool 55, binder 5
10	1	619	M	18	10	50	40		4	Vermiculite 62, binder 20
		564	M	20	5	15	80		4	Vermiculite 70, binder 10
		689 D	M	20	20	50	30	S	3	Vermiculite 75, perlite 5
		511 D	C	15						Vermiculite 74, clay 5
11	1	624	M	20	30	65	5	S	4	Vermiculite 65, binder 10
		700	M	15	10	90	0	S	7	Vermiculite 65, binder 20
		702 D	M	12	35	60	5	S	5	Vermiculite 75, binder 10
		590 D	M	30	10	60	30	F,S	3	Vermiculite 60, binder 7
		590 QA	M	15	10	70	20			Vermiculite 60, carbonate clay 15
12	1	701	M	10	60	35	5	S	5	Vermiculite 80, binder 10
		561	M	15	15	84	1	S	1	Vermiculite 60, binder 25
		670 D	M	5	60	40	0	S	4	Vermiculite 85, binder 5-10

(continued)

Table 10 (continued)

School no.	Site	Bulk sample no.[a]	Analysis lab[b]	Chrysotile volume %	Fiber size[c] (by %) F	M	L	Coat[d]	R.R[e]	Nonasbestos components volume %
		593 D	C	20						Vermiculite 50, other glass 20, gypsum 5, carbonate 5
12	2	688	M	10	80	20	0	S	5	Vermiculite 80, binder 10
		538	M	25	25	75	0	F,S	4	Vermiculite 50, binder 25
		506 D	M	17	95	5	0	S	2	Vermiculite 60, binder 20
		573 D	M	20	20	80	0	F,S	4	Vermiculite 50, binder 30
13	1	555	M	15	100	0	0		3	Perlite 85
		518	M	10	100	0	0		5	Perlite 90
		509 D	M	8	100	0	0		4	Perlite 90
		536 D	C	2						Perlite 27, carbonate 67, clay 3
13	2	679[f]	M	10	100	0	0		4	Perlite/gypsum 85
		679[f]	M	10						Vermiculite 50, binder 35
		515[f]	M	5	100	0	0		7	Perlite/binder 90-95
		515[f]	M	5						Vermiculite 50, binder 45
		609 D[f]	M	10	100	0	0		6	Perlite/binder 89
		609 D[f]	M	8						Vermiculite 40, binder 50
		556 D[f]	M	15	100	0	0	F	5	Perlite 85
		556 D[f]	M	10						Vermiculite 65, binder 25
		556 QA	M	7	50	40	10			Perlite 10, vermiculite 70 binder 13
13	3	628[f]	M	10	100	0	0		5	Perlite/binder 90
		628[f]	M	18						Vermiculite 50, binder 30
		571[f]	M	15	100	0	0		4	Perlite 85
		571[f]	M	12						Vermiculite 60, binder 25
		571 QA	M	8						Perlite 20, vermiculite 60, carbonate 10

(continued)

Table 10 (continued)

School no.	Site	Bulk sample no.[a]	Analysis lab[b]	Chrysotile volume %	Fiber size[c] (by %) F	M	L	Coat[d]	R.R[e]	Nonasbestos components volume %
		512 D[f]	M	15	100	0	0		6	Perlite 60, binder 25
		512 D[f]	M	8						Vermiculite 67, binder 25
		671 D	C	2						Perlite 53, carbonate 32, vermiculite 5, gypsum 4
14	1	618	M	10	5	90	5	S	3	Vermiculite/binder 90
		637	M	14	25	75	0	S	2	Vermiculite 60, binder 20, coating 5
		637 QA	M	10						Vermiculite 80, binder 5, opaques 5
		661 D	M	10	25	75	0	S	3	Vermiculite/binder 90
		582 D	C	10						Vermiculite 75, binder 10
14	2	530	M	18	10	80	10	S	7	Vermiculite 70, binder 10
		528	M	10	10	90	0		4	Vermiculite 60, binder 30
		528 QA	M	12	30	50	20			Vermiculite 75, binder 10
		574 D	M	15	10	80	10	S	3	Vermiculite 60, binder 23
		567 D	M	20	5	75	20	F	6	Vermiculite 60, binder 15
		567 QA	M	10	20	70	10			Vermiculite 80, binder 10
14	3	503	M	20	80	15	5	F,S	5	Vermiculite 60, binder 10, cellulose 5, surface coat 5
		627	M	5	15	80	5		3	Vermiculite 60, binder 25
		627 QA	M	7	20	70	10			Vermiculite 80, binder 8, cellulose 5
		687 D	M	10	75	25	0		4	Vermiculite 70, binder 10
		614 D	M	15	30	60	10		5	Vermiculite 55, binder 25

(continued)

Table 10 (continued)

School no.	Site	Bulk sample no.[a]	Analysis lab[b]	Chrysotile volume %	Fiber size[c] (by %) F	M	L	Coat[d]	R.R[e]	Nonasbestos components volume %
15	1	616	M	45	0	10	90		2	Glass wool 50
		565	M	40	0	10	90		3	Glass wool 55
		565 QA	M	30	10	20	70			Glass wool 30, carbonate 1
		535 D	M	35	0	5	95		4	Glass wool 65
		642 D	C	30						Glass wool 35, carbonate 3
16	1	519	M	20	10	65	25		4	Vermiculite 75, binder 5
		543	M	21	5	90	5		5	Vermiculite 59, binder 20
		675 D	M	20	10	30	60		6	Vermiculite 70, binder 10
		586 D	M	25	5	90	5	S	7	Vermiculite 50, binder 25
17	1	601	M	8	100	0	0	S	4	Vermiculite 60, binder 20
		526	M	15	95	5	0	F	4	Vermiculite 45, binder 40
		526 QA	M	10	60	40	0			Vermiculite 80, binder 10
		569 D	M	15	90	10	0	F	3	Vermiculite 50, binder 30
		550 D	C	10						Vermiculite 45, carbonate binder 10, gypsum 8
18	1	635	M	10	95	5	0		5	Perlite/binder 90
		635	M	20						Vermiculite 55, binder 25
		666	M	10	100	0	0		4	Perlite/binder 90
		566 D	M	8	100	0	0		2	Perlite 70, binder 20
		572 D	M	15	95	5	0		4	Perlite/binder 80, cellulose 5
19	1	560	M	40	40	50	10		8	Perlite 60
		560 QA	M	15	60	40	0			Perlite 60, carbonate 25
		607	M	12	90	5	5		7	Perlite 73, binder 10
		547 D	M	25	25	75	0		7	Perlite 75
		563 D	M	33	15	65	20		8	Perlite 66

(continued)

Table 10 (continued)

School no.	Site	Bulk sample no.[a]	Analysis lab[b]	Chrysotile volume %	Fiber size[c] (by %) F	M	L	Coat[d]	R.R[e]	Nonasbestos components volume %
20	1	693	M	16	99	1	0		7	Perlite 60, binder 24
		549	M	16	99	1	0		6	Perlite 70, binder 14
		589 D	M	12	70	25	5	F	7	Perlite 60, binder 28
		584 D	M	30	5	75	20		7	Perlite/binder 70
		584 QA	M	20	50	50	0			Perlite 65, carbonate 15
20	2	505	M	14	75	25	0	F	9	Perlite 80, binder 6
		659	M	12	50	30	20		8	Perlite 90-95
		625 D	M	20	10	60	30		9	Perlite/binder 78
		641 D	M	12	30	60	10		7	Perlite 80, binder 8
21	1	522	M	15	85	15	0		8	Perlite 65, binder 20
		630	M	18	80	20	0		8	Perlite 70, binder 11
		605 D	M	16	80	15	5		6	Perlite 70, binder 12
		539 D	C	24						Perlite 40, carbonate 28
21	2	653	M	14	15	75	10		9	Perlite 70, binder 16
		513	M	14	20	80	0		8	Perlite 70, binder 14
		544 D	M	15	95	5	0		7	Perlite 70, cellulose 15
		644 D	M	22	25	25	50		8	Perlite 70, binder 3
22	1	602	M	25	25	65	10	S	3	Vermiculite 50, binder 20
		668	M	20	60	40	0	S	4	Vermiculite 70, binder 5-10
		683 D	M	40	70	25	5	S	3	Vermiculite 50, binder 10
		516 D	M	40	50	49	1		4	Vermiculite 50, binder 10
22	2	583	M	35	10	85	5	S		Vermiculite 45, binder 20
		600	M	22	60	30	10	F,S	5	Vermiculite 60, binder 15, cellulose 5
		608 D	M	30	20	75	5	S		Vermiculite 60, binder 10
		676 D	M	15	40	60	0	F,S	5	Vermiculite 75, binder 10

(continued)

Table 10 (continued)

School no.	Site	Bulk sample no.[a]	Analysis lab[b]	Chrysotile volume %	Fiber size[c] (by %) F	M	L	Coat[d]	R.R[e]	Nonasbestos components volume %
23	1	638	M	8	99	1	0		6	Perlite 70, binder 28
		553	M	16	45	50	5	F	7	Perlite 60, binder 14
		684 D	M	12	90	9	1		6	Perlite 70, binder 18
		529 D	C	19						Perlite 53, carbonate 20, gypsum 4
24	1	610[f]	M	6	100	0	0		4	Perlite 5, vermiculite 80
		610[f]	M	9						
		559[f]	M	10	100	0	0		5	Perlite 5-10, vermiculite 70
		559[f]	M	8						
		651 D[f]	M	5						Perlite 20, vermiculite 75
		651 D[f]	M	11	100	0	0		4	
		591 D	C	8						Perlite 20, vermiculite 42 carbonate 25
24	2	546	M	18	25	50	25	F	7	Vermiculite 70, binder 12
		597	M	18	5	25	75	S	6	Vermiculite 72, binder 10
		685 D	M	15	75	20	5			Vermiculite 65, binder 20
		514 D	C	20						
25	1	507	M	5	100	0	0	F,S	7	Vermiculite 70, binder 20, surface coat 5
		558	M	8	90	10	0	S	2	Vermiculite 60, binder 40
		652 D	M	7	100	0	0	F	7	Vermiculite 75, binder 10
		520 D	C	2						Vermiculite 49, carbonate cellulose 5
25	2	654	M	12	100	0	0	F,S	3	Vermiculite 70, binder 18
		595	M	10	100	0	0	F,S	5	Vermiculite 70, binder 20
		524 D	M	10	100	0	0	F	2	Vermiculite 40, binder 50
		578 D	M	5	99	1	0	F,S	6	Vermiculite 75, binder 20
		578 QA	M	5	60	40	0			Vermiculite 80, carbonate binder 12

(continued)

Table 10 (continued)

School no.	Site	Bulk sample no.[a]	Analysis lab[b]	Chrysotile volume %	Fiber size[c] (by %) F	M	L	Coat[d]	R.R[e]	Nonasbestos components volume %
25	3	531	M	15	100	0	0	F,S	3	Vermiculite 50, binder 30, cellulose 5
		587	M	5	100	0	0	F,S	4	Vermiculite 50, binder 40, cellulose 5
		587 QA	M	2						Vermiculite 85, carbonate
		695 D	M	15	100	0	0	F,S	5	Vermiculite 50, binder 25, surface coat 10
		606 D	C	6				S		Vermiculite 55, carbonate binder 6, gypsum 5

a QA indicates duplicate analysis by different MRI analyst. D indicates duplicate samples. A double sample was taken side by side at one of the three bulk sampling points at a site to provide a duplicate for quality assurance.

b The laboratory that analyzed the sample: M for Midwest Research Institute (MRI) and C for Colorado School of Mines Research Institute (CSMRI).

c Fiber size: Fine - single fiber of length and width difficult to pick out and mount.
Medium - single fiber or small bundles suitable to mount as they are for PLM.
Large - fibers and bundles of sufficient size that they would have to be subdivided or separated for PLM.

d Coating: S indicates that there was coating on the suface; F indicates that there was coating on the fibers themselves.

e Releasability rating.

f Double-layered sample, perlite surface exposed.

g CSMRI reported average of both layers.

CSMRI noted layering and prepared their samples for analysis to include a proportional amount of both layers. The subsample was then homogenized before slides were prepared for the PLM work. In most cases there was little difference in the asbestos content of the layers of any given sample.

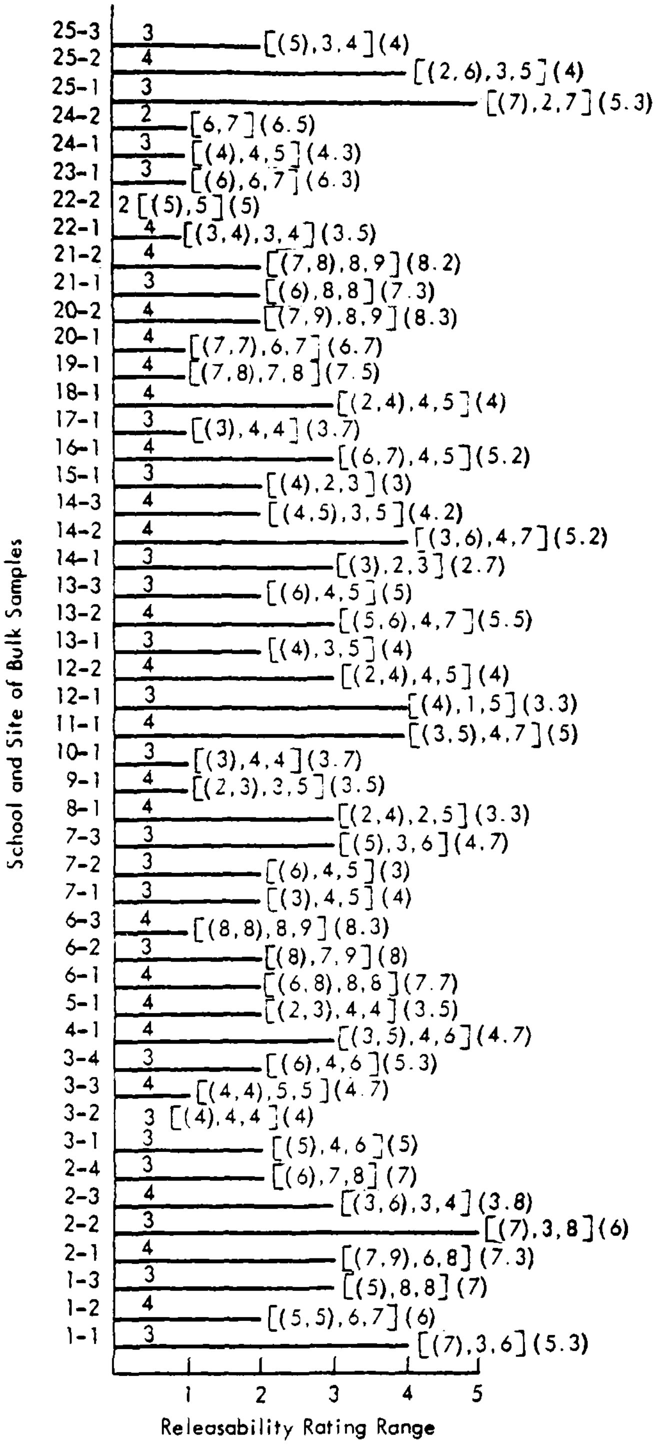
Characteristics other than the asbestos content that were observed from the analysis of the bulk samples included the fiber or fiber bundle size, the degree that the asbestos fibers were bound to the matrix or were coated with a binder, and the toughness or brittleness of the insulation matrix. These characteristics are not evident by sample examination without magnification, but differences between samples are readily seen under the low power magnification of a stereomicroscope. The fiber size and coating information are given, respectively, in columns 6 and 7 of Table 10.

Examination of the results indicated that there were three major matrix components (perlite, vermiculite, and glass wool), three dominant fiber sizes (fine, medium, and coarse), two fiber coat categories (coated and not coated), and four major ranges of asbestos content (0-10%, 10-20%, 20-30%, and greater than 30% by volume).

The question arose as to whether this information was related to air levels of asbestos. Tentative subjective ratings of these data according to the apparent availability of releasable fibers from the bulk material indicated a possible relationship between the ratings and the air levels. Therefore, each bulk sample was reexamined with a low power stereomicroscope and rated on an arbitrary scale of 1 through 9 for the apparently available free asbestos fibers, or the asbestos releasability factor. The results of this subjective rating, which was based on asbestos content, fiber size, brittleness of the matrix, and apparent freedom of the individual asbestos fibers, are shown in Figure 3.

The numbers on the ordinate identify the schools and the sites at the schools where the bulk samples were taken. Of the 48 school sites, 23 sites had three bulk samples rated, 23 sites had four bulk samples rated, and 2 sites had two bulk samples rated. The abscissa gives range of releasability. The horizontal lines represent the range of releasability (1 to 5) of the samples taken from a site. The numbers appearing above the horizontal lines represent the number of bulk samples taken from a site that were rated for releasability. The numbers in brackets to the right of the horizontal lines are the releasability ratings, on a scale of 1 to 9, of each bulk sample taken from a site. The numbers in parentheses within the brackets are the duplicate samples. The number in parentheses to the right of the brackets is the average of the values within the brackets. The average was calculated by first averaging the duplicates and then using that value with the remaining values in the brackets to calculate the average number in parentheses to the right of the brackets.

The information in Figure 3 indicates that there is a significant variation in releasability rating values among those samples taken from the same site. The largest spread in releasability ratings for a set of samples from a site is 5; the lowest is zero; and the average of all 48 sites is 2.3. The reason for this variability can be that the material on the ceiling at a site



NOTES

1. The numbers running vertically at the left identify the schools and the sites at the schools where the bulk samples were taken. Of the 48 school sites, 23 sites had three bulk samples rated, 23 sites had four bulk samples rated, and 2 sites had two bulk samples rated.

2. The horizontal lines represent the range of releasability (1 to 5) of the samples taken from a site.

3. The numbers appearing above the horizontal lines represent the number of bulk samples taken from a site that were rated for releasability.

4. The numbers in brackets to the right of the horizontal lines are the releasability ratings, on a scale of 1 to 9, of each bulk sample taken from a site. The numbers in parentheses within the brackets are the duplicate samples. The number in parentheses to the right of the brackets is the average of the values within the brackets. The average was calculated by first averaging the duplicates and then using that value with the remaining values in the brackets to calculate the average number in parentheses to the right of the brackets.

Figure 3. Releasability ratings and the range of the ratings of bulk samples from each of the 48 sites sampled.

is not homogeneous, that the subjectivity bounds are that great, or both. It may well be that more experience in this type of rating could narrow the variability bounds in the rating. The spread in the asbestos content for sets of bulk samples is considerably less than the spread in the releasability ratings. This releasability work was statistically analyzed, and the results are given in Section 7.

C. Quality Assurance

All samples were handled according to the sample handling procedure given in the protocol for Sampling and Analysis of Insulation Material Suspected of Containing Asbestos, which can be found in Appendix D. Neither the relationship of the samples with each other nor their individual source was known to the analyst. The Protocol for Creating and Maintaining Chain of Custody, which can be found in Appendix C, was followed by MRI.

The side-by-side duplicate samples were divided blindly and at random into two groups of 24 each. One set of samples was sent to CSMRI for analysis. In addition, 10% of all samples retained at MRI were randomly selected and given an independent examination by a second MRI analyst.

The CSMRI analyst prepared four to five representative subsamples from each of the 24 quality assurance bulk samples. Each of these macrosize subsamples was thoroughly mixed using tweezers. From these subsamples, three slides were prepared as oil dispersion mounts of portions of the material for examination through a polarizing microscope with a 60-W tungsten light source, set up for 44X and 125X magnification. Components were identified on the basis of morphology, refractive index, and other optical properties. Quantitation was achieved by observing the microsize subsamples with the microscope.

The analytical procedures used by CSMRI were basically the same as those used by MRI, but there were some differences. MRI included a low power stereomicroscopic examination for determining sample layering and gross uniformity. Also, MRI used a polarizing light microscope equipped with a dispersion staining objective as an aid in refractive index determination. PLM examinations by MRI were made at the single magnification of 100X.

The results of the quality assurance analyses in terms of percentage relative variation (standard deviation divided by mean, multiplied by 100) are as follows. For the MRI laboratory replications, the relative variation was 36%. This value may be interpreted as an estimate of analytical error associated with PLM. For the side-by-side duplicate samples, the relative variation for samples analyzed at MRI was 52%; for the samples that were divided between MRI and CSMRI, the relative variation was 57%. The relative variation observed at MRI (52%) is an estimate of variation consisting of three components--side-by-side sampling variation, intralaboratory variation, and analytical error. The relative variation observed between MRI and CSMRI (57%) is an estimate of variation based on four components--side-by-side sampling variation, intralaboratory variation, interlaboratory variation, and analytical error.

These error levels are consistent with error estimates reported in the literature for PLM (USEPA 1982b). The small difference in analysis of side-by-side samples between MRI and CSMRI (52% versus 57%) indicates that the PLM protocol was well controlled.

An alternate view of the quality of the bulk sample data is found in a direct analysis of the variance components for these measurements. An analysis of variance components was conducted using VMCPNLS, a general purpose program for a completely nested, multistage design (Shah 1979). The variance components are summarized by percentage contribution in Table 11. The variation across schools and sites, which are the primary variables being studied, far exceeds the variation due to sampling and laboratory analysis. These results indicate that the sampling and analysis protocols were in control at a level sufficient to produce data that are consistent with their intended use in the study.

Table 11. Variance Components for PLM Measurement of Bulk Samples

Component	Percentage of total variation[a]
Schools	53
Sites	31
Location	7
Side-by-side	7
Laboratory replication	2

a Rounded to the nearest percent.

SECTION 7

STATISTICAL ANALYSIS

A major emphasis of this study was the statistical analysis of the data collected at the sites in the schools. The main purpose of this analysis was to document the air levels, bulk levels, assessment factors, and algorithm scores, and then to examine the relationships between these levels and the factors and scores. In particular, it was of interest to determine how well airborne asbestos levels could be predicted by the various variables one at a time and in combination. Since amphibole levels were generally scarce, only chrysotile data were analyzed.

As in any data analysis, a great many exploratory analyses were carried out with the data, a subset of which produced useful results. Accordingly, this section describes principal results and does not present the many preliminary analyses that were undertaken. The following results are reported in this section.

(1) Average airborne chrysotile levels by general location (ambient, indoor control, asbestos-containing material site);

(2) Average airborne chrysotile levels by individual assessment factors;

(3) Average airborne chrysotile levels by a dichotomized algorithm score;

(4) Airborne chrysotile values by bulk chrysotile percentage and bulk sample components;

(5) Average airborne chrysotile levels by bulk sample releasability;

(6) Average airborne chrysotile levels by cleaning category; and

(7) Variability of airborne chrysotile values over time.

The analysis methods used are discussed in more detail in the following subsection. The regression analyses are focused upon the relationship between airborne chrysotile values and a set of possible predictors or independent variables. The best-predicting regression equations have been identified by examining the empirical performance of various candidate models. Alternative classification analyses are also discussed. These analyses are focused upon predicting whether or not the airborne chrysotile level at a specified site is higher or lower than some specified reference level. The classification analyses include unweighted discriminant analyses, two analyses based upon an algorithm score dichotomy or a releasability dichotomy, a series of analyses based upon regression models, and a series of decision tree analyses based upon the assessment factors and/or releasability.

I. ANALYSIS METHODS

The summary statistics presented in this section quite often include three measures of central tendency, namely, the arithmetic mean, the median, and the geometric mean. The arithmetic mean is given because it is the most familiar measure of central tendency; however, it can be unduly inflated when the distribution of the data is highly skewed. In the present case, the distribution of air levels does appear to be skewed; therefore, the geometric mean and median are also presented. These latter two statistics are considered better measures of central tendency for skewed data.

Probability values (p-values) from statistical tests of hypotheses concerning means and correlations are presented in tables and figures. Formally, the p-value associated with means indicates the probability of erroneously rejecting the statistical hypothesis that the means of interest are equal, whereas the p-value associated with a correlation indicates the probability of erroneously rejecting the statistical hypothesis that the correlation of interest is zero. Practically, the p-value associated with means indicates whether or not the size of the difference between means can be attributed to random variation, whereas the p-value associated with a correlation indicates whether or not the size of the correlation can be attributed to random variation. The smaller p-values indicate a larger statistical difference between means, or between a correlation and zero, while the larger p-values indicate a smaller statistical difference between means, or between a correlation and zero.

In most cases, population estimates (weighted estimates) are presented rather than unweighted estimates. This reflects the fact that the data collected in this project were collected under a probability sampling framework; therefore, by taking this into account (i.e., by correctly weighting the data), estimates for the entire urban school district may be obtained even though all schools in the district were not sampled. For example, when the population mean of air levels for asbestos-containing sites is presented, this is an estimate of the mean for all asbestos-containing student activity sites in the entire urban school district. In those cases where unweighted estimates are given (i.e., estimates that ignore the sampling weights), this reflects the fact that preliminary statistics are being examined before the final weighted estimates are presented.

In the analyses presented in this section, the factor scores used are the consensus scores of all five raters. This was done to avoid an excessive number of analyses and because analysis of rater differences did not indicate large rater-to-rater disagreement.

II. AIRBORNE CHRYSOTILE CONCENTRATION AT ASBESTOS-CONTAINING MATERIAL SITES, CONTROL SITES, AND OUTDOOR AMBIENT SITES

A. Exposure Levels

The first objective of this study was to document probable exposure to airborne asbestos resulting from asbestos-containing materials in schools. In general, higher levels of airborne chrysotile were found in student activity areas with asbestos-containing materials, and relatively lower levels of airborne chrysotile were found in student activity areas without asbestos-containing materials (indoor controls in schools with asbestos-containing material sites). The lowest levels were found at ambient sites on the roofs of the schools.

Table 12 gives the estimated air levels of chrysotile for the asbestos-containing material sites, the control sites, and the ambient sites. Reading from Table 12, the average air level of chrysotile in asbestos-containing material sites is 179.46 ng/m^3 with a standard error of the mean of 41.99 ng/m^3. The geometric mean is 80.45 ng/m^3 with a standard error of 23.62 ng/m^3. The minimum value observed is 0 ng/m^3, the maximum is 644 ng/m^3, and the median is 92.70 ng/m^3. These population estimates are based on a sample of 48 asbestos-containing material sites. It is estimated that there are 2,698 asbestos-containing material sites in the school district.

The test of difference in air level means among asbestos-containing material sites, control sites, and ambient sites is significant at the level $< .01$ For geometric means, this test is significant at the level $< .01$. Additionally, differences in air level means and geometric means were tested between pairs of site types. The levels of significance are as follows: asbestos-containing material versus ambient, mean significant at $< .01$ (geometric mean significant at $< .01$); control versus ambient, .03 (.03); and asbestos-containing material versus control, .01 (.02). These test results indicate that generally exposure to airborne asbestos is higher in rooms containing asbestos materials than in rooms without. The results also indicate that airborne asbestos levels inside buildings with asbestos materials are higher than outdoor ambient levels.

Figure 4 contains a boxplot of airborne chrysotile levels based upon the 48 asbestos-containing material sites, 19 of the indoor control sites, and 25 ambient sites. (Two control sites were omitted because friable material was found, and four were omitted because they were not student activity areas.) The boxplot emphasizes the airborne chrysotile gradient observed in the present study; for example, the 25th percentile of the airborne chrysotile distribution at the asbestos-containing material sites is only slightly larger than the 50th percentile (median) observed at the indoor control sites. A similar shifting of the airborne chrysotile distributions is evident when the data from the control sites are compared to the data from the ambient sites.

Table 12. Airborne Chrysotile Concentration (ng/m^3) for Asbestos-containing Friable Material Sites, Control Sites, and Ambient Sites

Population estimates	Asbestos-containing friable material sites	Control sites	Ambient sites
Mean ($p < .01$)[a]	179.46	53.09	6.10
Standard error of the mean	41.99	19.64	4.34
Geometric mean ($p < .01$)[b]	80.45	13.15	2.16
Standard error of the geometric mean	23.62	8.35	1.07
Minimum	0.00	0.00	0.02
Median	92.70	21.80	0.90
Maximum	644.00	362.00	40.60
Number of sample sites	48	19[c]	25
Estimated number of population sites	2,698	2,077	109

a Test of difference (in airborne chrysotile means) among asbestos-containing friable material sites, control sites, and ambient sites: level of significance < .01.

b Test of difference (in airborne chrysotile geometric means) among asbestos-containing friable material sites, control sites, and ambient sites: level of significance < .01.

c Of the twenty-five control sites, two were omitted because asbestos-containing friable material was found, and four were omitted because they were not student activity areas.

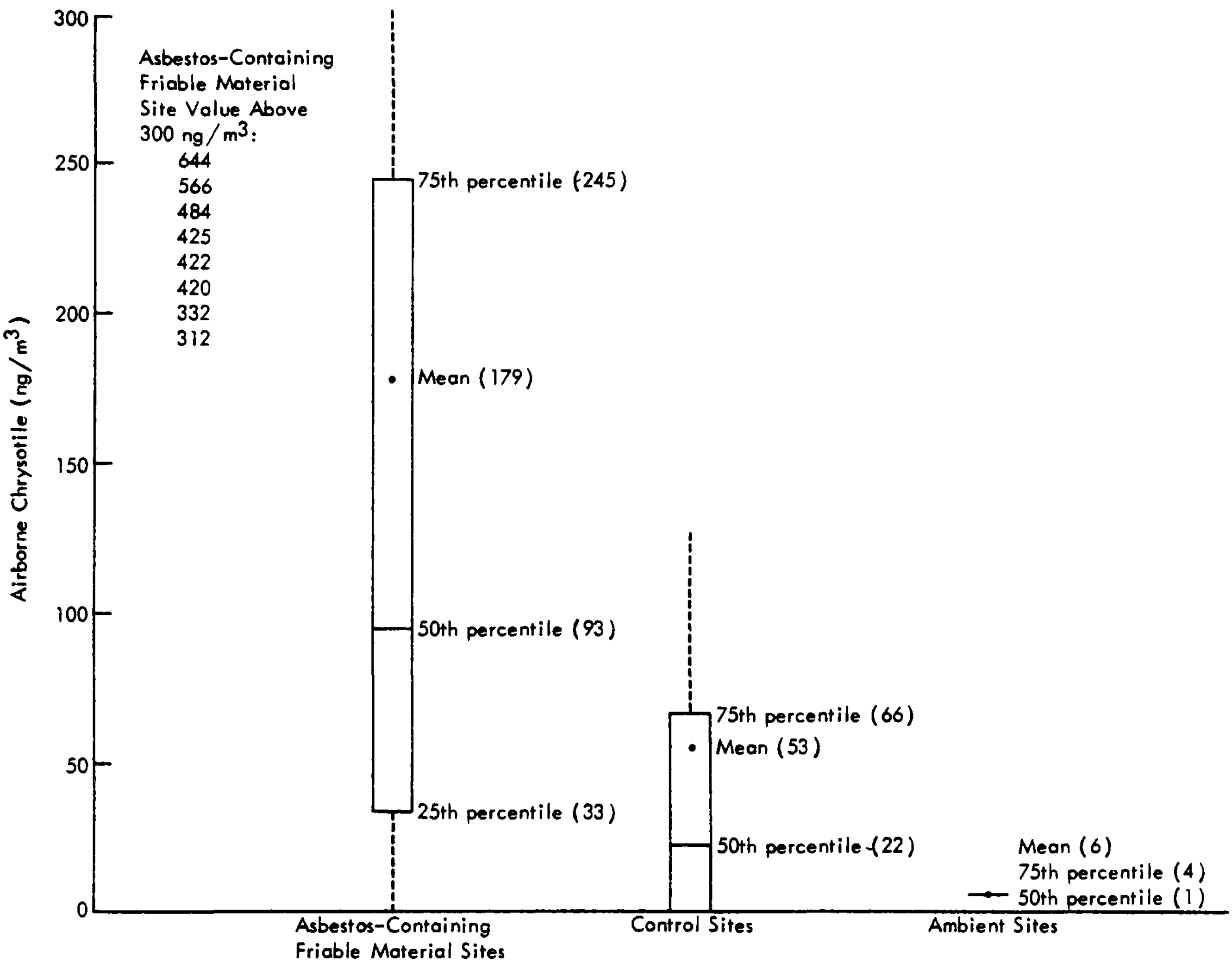


Figure 4. Boxplot of airborne chrysotile concentrations (ng/m^3) for asbestos-containing material sites, indoor control sites, and outdoor ambient sites (population estimates).

B. Schoolwide Elevated Levels

As discussed in the preceding subsection, the average airborne chrysotile level is significantly higher for control sites, as well as for asbestos-containing material sites, than for ambient sites. This result demonstrates that exposure to airborne asbestos probably occurs beyond those sites which actually contain the asbestos materials.

In 15 of the 25 sample schools, the air level of chrysotile in the control site appears to be elevated above the ambient site's level. Air sampling results for these 15 schools are listed in Table 13. In nine of the schools, the control site's air level of chrysotile exceeds the air level of chrysotile in at least one of the school's asbestos-containing material sites.

When the analytical focus shifts from the school district level of aggregation to the individual school level, a problem develops. Specifically, this study was designed to yield reasonably precise estimates for the school district as a whole. Hence, the sample sizes within schools are too small to yield precise estimates at that level. Indeed, the precision or the variance of an estimate cannot be obtained when there is only one observation of a kind at a school (e.g., a single indoor or outdoor control site). Thus, due caution should be exercised when comparing individual airborne chrysotile values (asbestos-containing material site/inside control/outside control) at the school level.

The transport of airborne asbestos from its source to other school areas is not fully understood. In this study, any student activity area without asbestos-containing material was eligible to be an indoor control site; there was no requirement that indoor control sites be a certain distance from asbestos-containing material sites. Any further consideration might include airflow and ventilation, traffic patterns, etc. In the second school (School 3) on the list in Table 13, all student activity areas have asbestos-containing material. An office was selected as the control site for this school, and the hallway outside the office and classrooms near the office had asbestos-containing material. In light of this, it is reasonable to expect an elevated air level of chrysotile in this control site. A different situation is present in the sixth school on the list (School 10). The only asbestos-containing material in the school is in the asbestos-containing material site sampled and small areas close to it. The control site is located on the floor above, where there are no sites with asbestos-containing material. For this school, a reasonable explanation of the elevated air level of chrysotile observed in the control site is not immediately obvious.

C. Levels of the Assessment Factors

Tables 14 through 21 describe the air levels of chrysotile at asbestos-containing material sites, by factor levels, for each of the following assessment factors: condition of material, accessibility, airstream status, exposure, water damage, activity level, friability, and chrysotile content. Table 22 summarizes results of testing differences in air level geometric means among levels of each factor. Differences were found to be significant for chrysotile content. None of the other differences were found to be significant.

Table 13. Schools Where Airborne Chrysotile Concentration at Indoor Control Site Appears to be Elevated Above Concentration at Outdoor Ambient Site

School no.	Airborne chrysotile concentration (ng/m^3)		
	Ambient site	Control site	Asbestos-containing friable material sites
1	0.40	69.30	28.40 8.95 108.00
3	2.70 (W1)[a] 17.60 (W2) 0.00 (W3)	166.00 (W1) 14.60 (W2) 45.50 (W3)	105.00 (W1) 27.50 (W2) 6.17 (W3) 11.00 38.20 332.00
5	1.44	16.90	23.60
6	0.36	43.90	37.00 82.80 43.00
8	0.30	362.00	0.10
10	0.55 (W1) 10.80 (W2) 1.10 (W3)	72.90 (W1) 50.30 (W2) 73.40 (W3)	10.00 (W1) 0.76 (W2) 1.50 (W3)
11	0.90	51.00	11.20
14	0.77	49.80	77.60 150.00 80.00
15	3.50	21.80	69.30
16	2.50	69.30	425.00
18	0.57	46.80	7.93
20	0.35	288.00	420.00 566.00
21	0.63	19.00	153.00 484.00
24	0.38	25.20	77.80 11.00
25	1.30	116.00	8.58 4.30 245.00

a W1 = sampling week 1; W2 = sampling week 2; and W3 = sampling week 3.

Table 14. Airborne Chrysotile Concentration (ng/m^3) for Asbestos-containing Friable Material Sites by Condition of Material

Population estimates	Condition: No damage	Moderate damage	Severe damage	Total
Mean (p = .24)[a]	206.28	121.76	NA*	179.46
Standard error of the mean	56.90	37.15	NA	41.99
Geometric mean (p = .15)[a]	103.58	45.99	NA	80.45
Standard error of the geometric mean	36.60	18.80	NA	23.62
Number of sample sites	32	16	0	48

a Level of significance for test of difference between means.
* NA = not applicable.

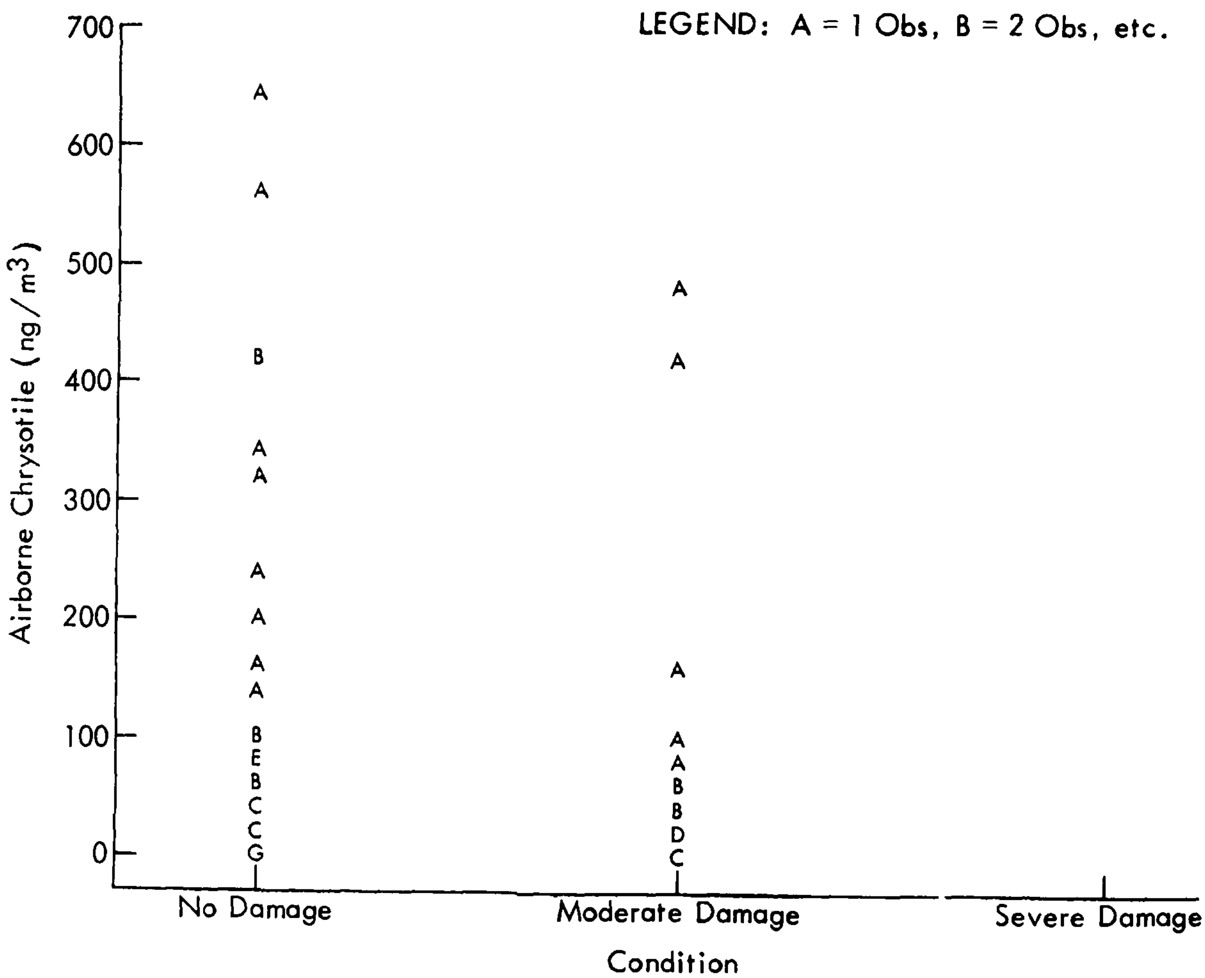


Table 15. Airborne Chrysotile Concentration (ng/m^3) for Asbestos-containing Friable Material Sites by Accessibility of Material

Population estimates	Accessibility: Not accessible	Accessibility: Rarely accessible	Accessibility: Accessible	Total
Mean (p = .99)[a]	NA*	179.34	180.92	179.46
Standard error of the mean	NA	45.41	124.87	41.99
Geometric mean (p = .49)[a]	NA	87.23	28.37	80.45
Standard error of the geometric mean	NA	25.59	44.06	23.62
Number of sample sites	0	44	4	48

a Level of significance for test of difference between means.
* NA = not applicable.

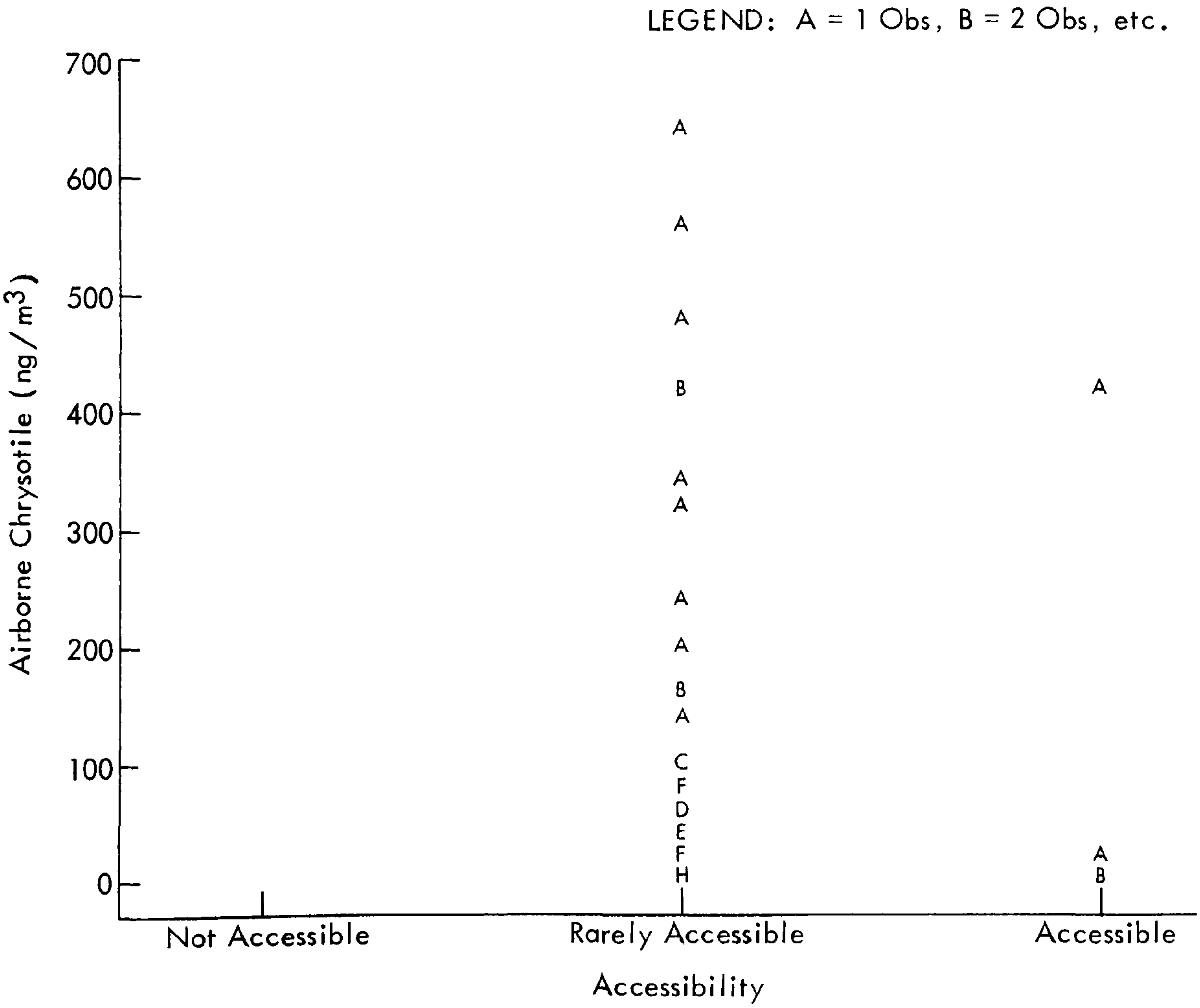


Table 16. Airborne Chrysotile Concentration (ng/m^3) for Asbestos-containing Friable Material Sites by Air Stream Status

Population estimates	Air Stream Status: Not in air stream	Air Stream Status: In air stream	Total
Mean (p = .08)[a]	115.89	239.86	179.46
Standard error of the mean	25.65	65.45	41.99
Geometric mean (p = .47)[a]	65.69	97.49	80.45
Standard error of the geometric mean	14.00	48.26	23.62
Number of sample sites	25	23	48

a Level of significance for test of difference between means.

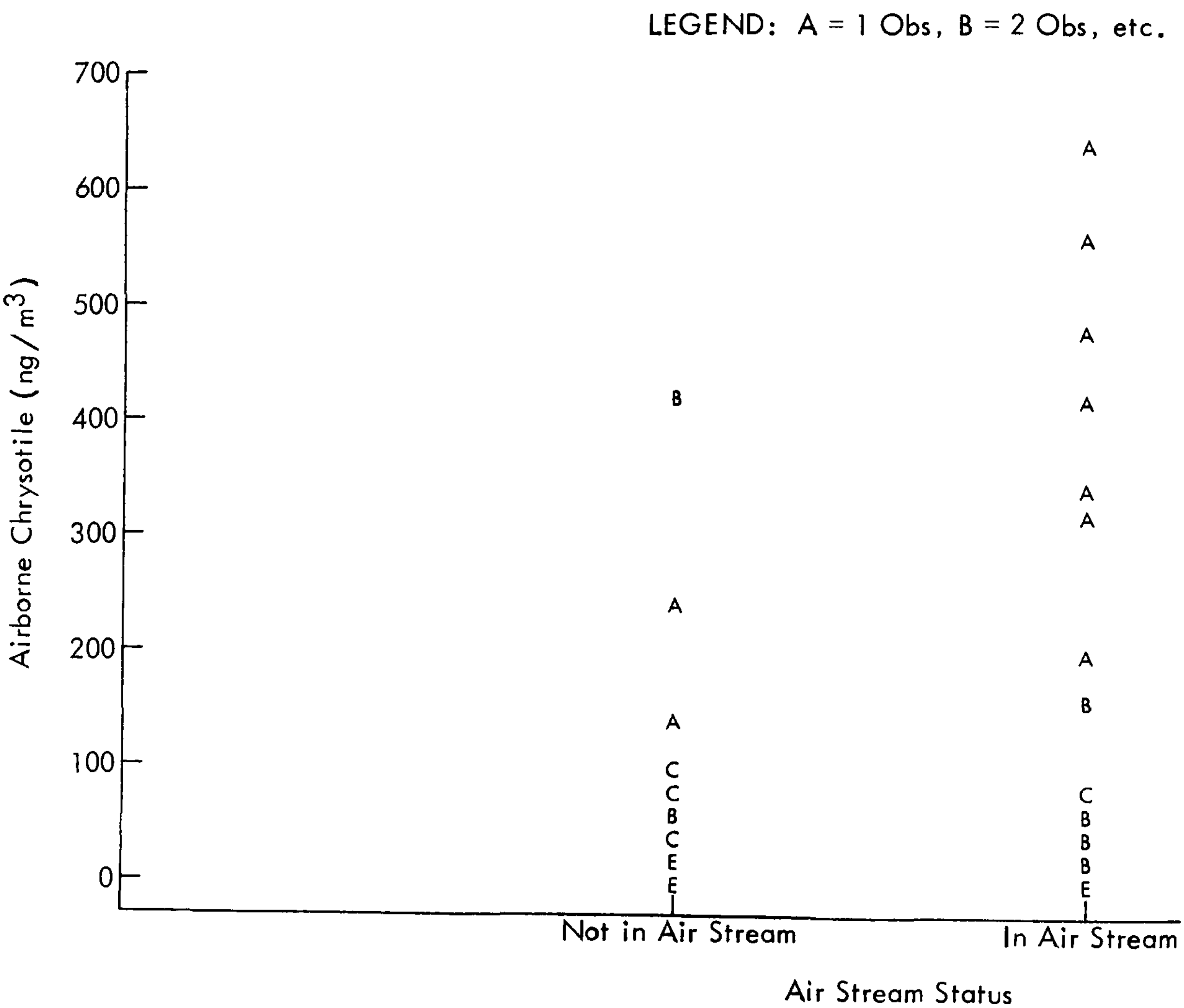


Table 17. Airborne Chrysotile Concentration (ng/m^3) for Asbestos-containing Friable Material Sites by Proportion of Material Exposed

Population estimates	Exposure: Not exposed	Exposure: 10% or less exposed	Exposure: Greater than 10% exposed	Total
Mean	NA*	NA	179.46	179.46
Standard error of the mean	NA	NA	41.99	41.99
Geometric mean	NA	NA	80.45	80.45
Standard error of the geometric mean	NA	NA	23.62	23.62
Number of sample sites	0	0	48	48

* NA = not applicable.

Table 18. Airborne Chrysotile Concentration (ng/m^3) for Asbestos-containing Friable Material Sites by Water Damage of Material

Population estimates	Water damage: None	Minor	Moderate or major	Total
Mean (p = .70)[a]	170.78	178.49	289.73	179.46
Standard error of the mean	65.77	36.37	126.89	41.99
Geometric mean (p = .28)[a]	57.56	120.51	164.67	80.45
Standard error of the geometric mean	27.52	25.52	109.34	23.62
Number of sample sites	30	13	5	48

a Level of significance for test of difference between means.

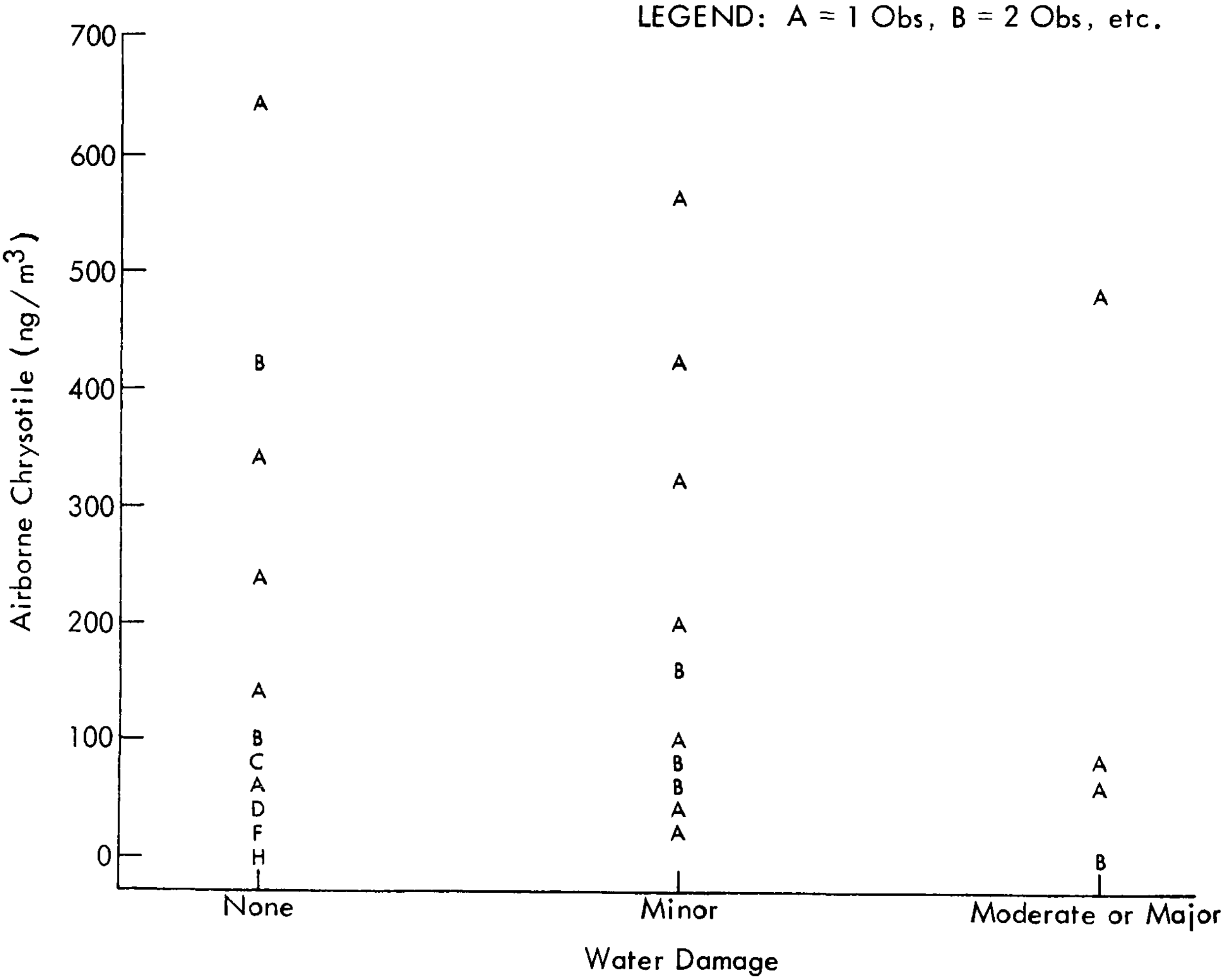


Table 19. Airborne Chrysotile Concentration (ng/m^3) for Asbestos-containing Friable Material Sites by Activity

Population estimates	Activity: None or low	Activity: Moderate	Activity: High	Total
Mean (p = .91)[a]	172.24	200.36	142.67	179.46
Standard error of the mean	42.58	89.32	92.07	41.99
Geometric mean (p = .76)[a]	83.77	94.58	39.85	80.45
Standard error of the geometric mean	33.91	43.01	40.44	23.62
Number of sample sites	25	18	5	48

a Level of significance for test of difference between means.

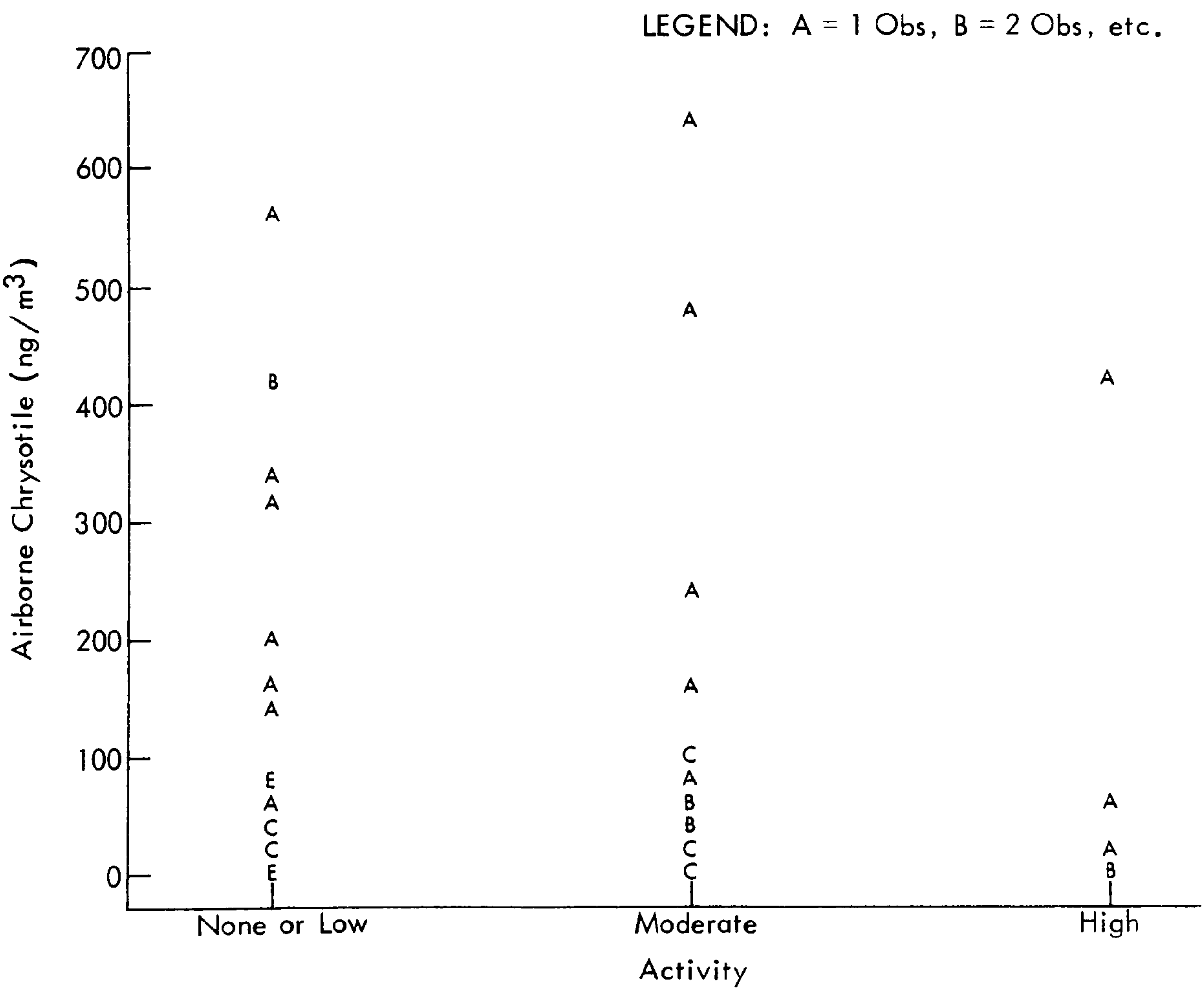


Table 20. Airborne Chrysotile Concentration (ng/m^3) for Asbestos-containing Friable Material Sites by Friability of Material

Population estimates	Friability Low	Moderate	High	Total
Mean (p = .28)[a]	199.86	187.12	99.00	179.46
Standard error of the mean	77.50	55.55	32.65	41.99
Geometric mean (p = .57)[a]	102.54	85.49	35.23	80.45
Standard error of the geometric mean	50.74	31.14	31.52	23.62
Number of sample sites	12	29	7	48

a Level of significance for test of difference between means.

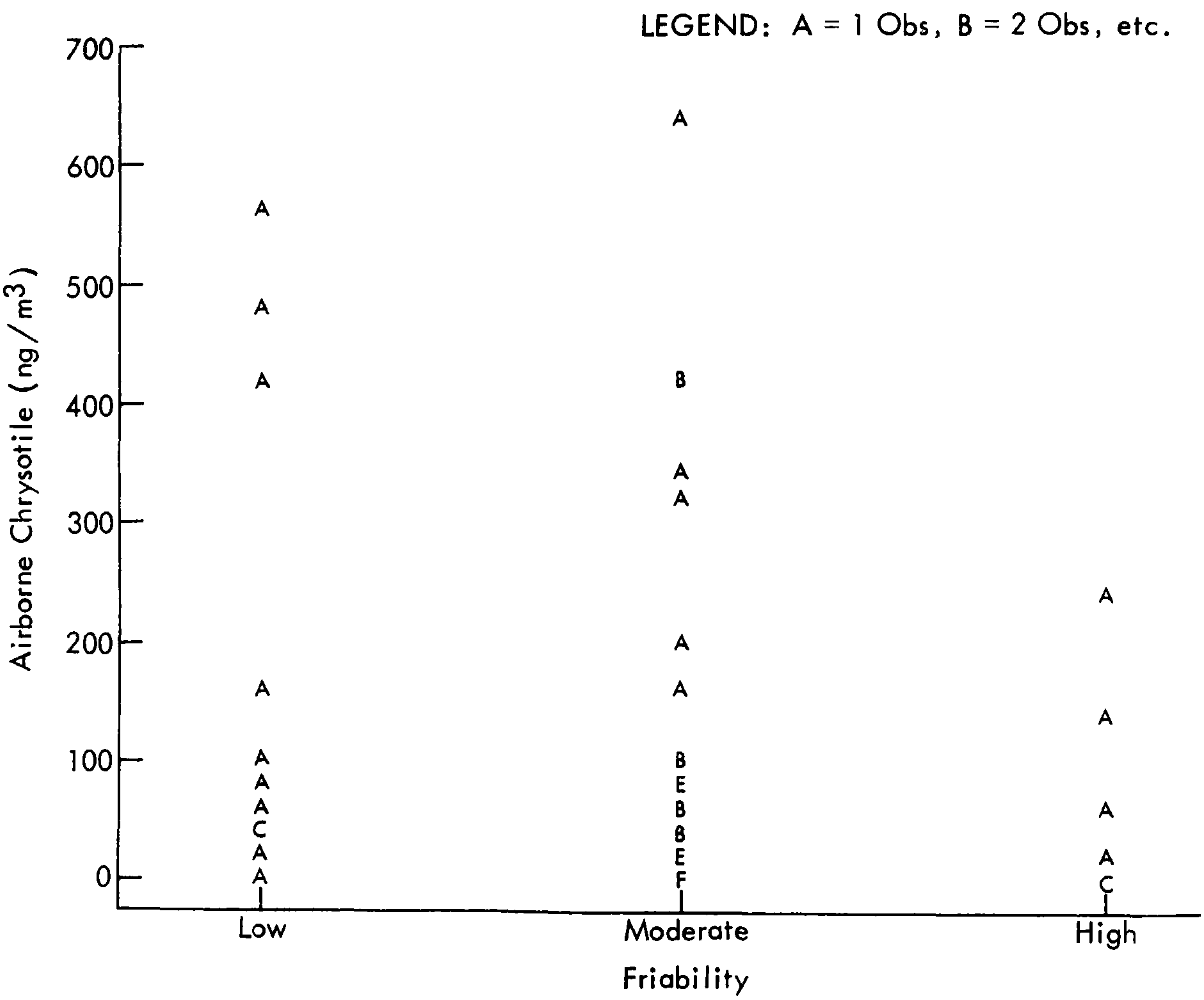


Table 21. Airborne Chrysotile Concentration (ng/m^3) for Asbestos-containing Friable Material Sites by Chrysotile Content[a] of Material

Population estimates	Chrysotile Content: Low (≦ 1%)	Moderate (> 1%, ≦ 50%)	High (> 50%)	Total
Mean ($p < .01$)[b]	NA[*]	184.72	0.96	179.46
Standard error of the mean	NA	42.74	0.07	41.99
Geometric mean ($p < .01$)[b]	NA	89.92	0.93	80.45
Standard error of the geometric mean	NA	24.55	0.10	23.62
Number of sample sites	0	46	2	48

a As categorized in the original algorithm.
b Level of significance for test of difference between means.
* NA = not applicable.

Table 22. Summary of Relationships Between Airborne Chrysotile Concentration (ng/m^3) and Original Algorithm Factors for Asbestos-containing Friable Material Sites

Algorithm factors	Sign of regression relationship[a]	Results of test[a]
Condition	-	NS[b]
Accessibility	-	NS
Air stream status	+	NS
Exposure	NA[c]	NA
Water damage	+	NS
Activity	-	NS
Friability	-	NS
Chrysotile content	-	Sig.[d]

a Based on geometric means (Tables 14-21).
b NS = not significant at .10 level.
c NA = not applicable.
d Sig. = significant at .10 level.

Though not significant, as water damage increases (from none to minor to moderate or major) the average air level of chrysotile increases. For the factors of activity, friability, and chrysotile content, though the differences among factor levels were not found to be significant, the directions of the relationships were not consistent with those expected. For example, among activity levels (Table 19), the average air level of chrysotile is lowest for high activity. In interpreting these results, it should be noted that only one factor at a time is being considered; i.e., there are no adjustments for extraneous factors.

These adjustments may be necessary because of the possible confounding effects of extraneous factors upon the relationship of interest. For example, when the relationship between friability and airborne chrysotile levels is being characterized, the possible effect of the bulk chrysotile percentage, and water damage could be taken into account by including friability, bulk chrysotile percentage, and water damage in an appropriate statistical model. Thus the bivariate analyses should be viewed as preliminary until the appropriate multivariate analyses are completed.

Table 20 describes air levels of chrysotile by the factor friability, which has three levels--low, moderate, and high. For sites with a friability rating of low, the mean air level of chrysotile is 199.86 ng/m^3 with a standard error of 77.50 ng/m^3. The geometric mean is 102.54 ng/m^3 with a standard error of 50.74 ng/m^3. There are 12 sample sites with a low friability rating, 29 sites moderate, and 7 sites high. Differences in geometric means among friability levels are very significant ($p = .57$). However, geometric means decrease (from 102.54 ng/m^3 to 85.49 ng/m^3 to 35.23 ng/m^3) as friability increases. This is the opposite of the relationship originally hypothesized--that levels of chrysotile increase as friability increases.

In Table 14, note that there are no sample sites with a condition rating of severe damage. It follows that no conclusions can be drawn from this study about the effect of severe damage on air level of chrysotile. Also, none of the sample sites has an accessibility rating of not accessible (Table 15). All 48 asbestos-containing material sites in the sample have the same exposure rating, greater than 10% exposed, so no comparisons of air levels for different exposure categories can be made (Table 17).

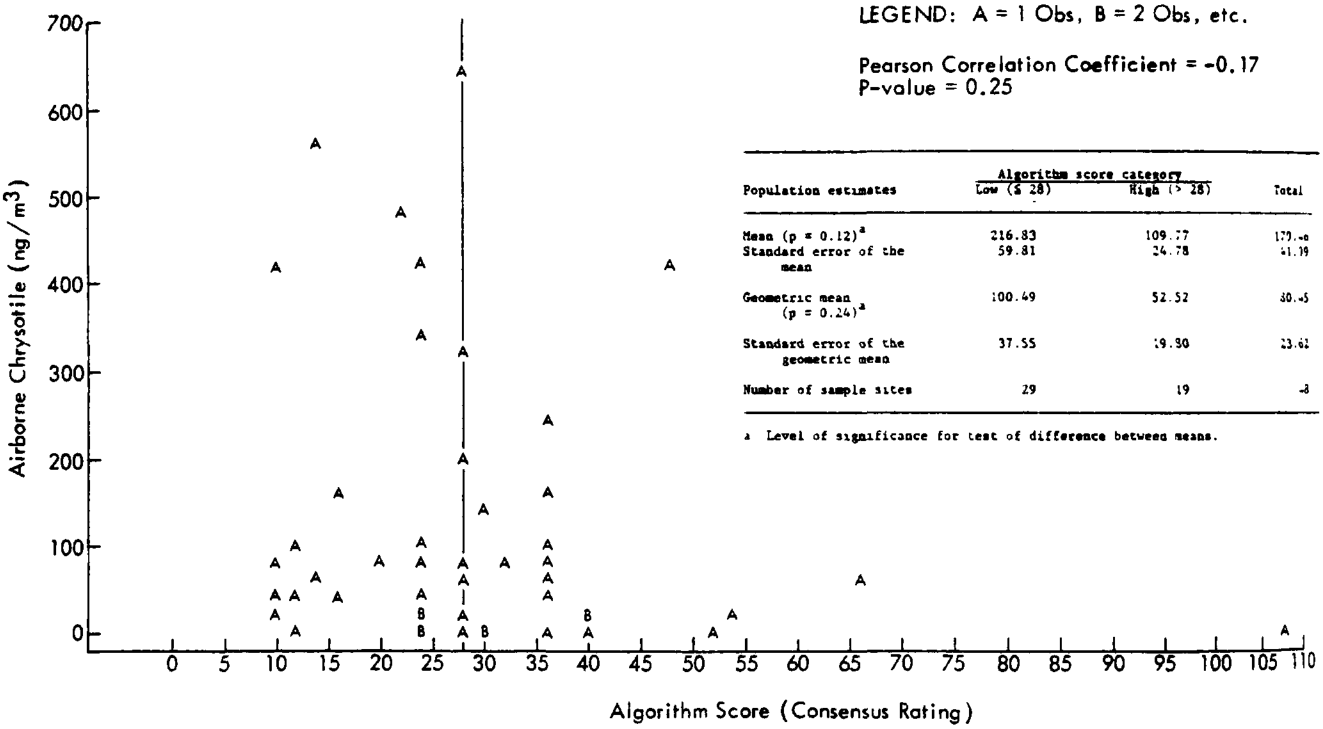
D. Algorithm Score

Table 23 gives the distribution of the exposure assessment algorithm scores (formed from consensus factor ratings) estimated for the asbestos-containing material sites in the school district. The mean score is 29 with a standard error of 3.2. The median score is 28. The information in Table 23 is useful for judging whether or not a given score value is high or low with respect to the score distribution in the school district.

Figure 5 is a plot of the air level of chrysotile versus the algorithm score for the 48 asbestos-containing material sites in the sample. The Pearson correlation coefficient (-0.17) is not significantly different from zero ($p = .25$). This indicates that there is no linear relationship between the algorithm score and the air levels of chrysotile observed during the study.

Table 23. Exposure Assessment Algorithm Scores for the Asbestos-Containing Material Sites in the School District

Population estimates	Exposure assessment algorithm score
Mean	29
Standard error of the mean	3
Minimum	10
Median	28
Maximum	108
Quantiles	
10	12
20	16
30	24
40	24
50	28
60	28
70	30
80	36
90	40
Number of sample sites	48
Estimated number of population sites	2,698



Population estimates	Algorithm score category Low (≤ 28)	High (> 28)	Total
Mean ($p = 0.12$)[a]	216.83	109.77	[illegible]
Standard error of the mean	59.81	24.78	41.39
Geometric mean ($p = 0.24$)[a]	100.49	52.52	80.45
Standard error of the geometric mean	37.55	19.80	23.62
Number of sample sites	29	19	48

a Level of significance for test of difference between means.

Figure 5. Airborne chrysotile concentration (ng/m^3) versus the consensus score rating for the 48 asbestos-containing material sites.

(A strong positive linear relationship would be exhibited by all points on the plot lying close to a straight line from lower left to top right).

The table in Figure 5 shows the air levels of chrysotile (population estimates) by algorithm score category. The low/high score division is made at the weighted median score of 28. The difference in geometric means between score categories is not significant. The difference in means has a p-value of .12, and the mean air level is lower for the high algorithm score category.

E. Bulk Chrysotile Levels

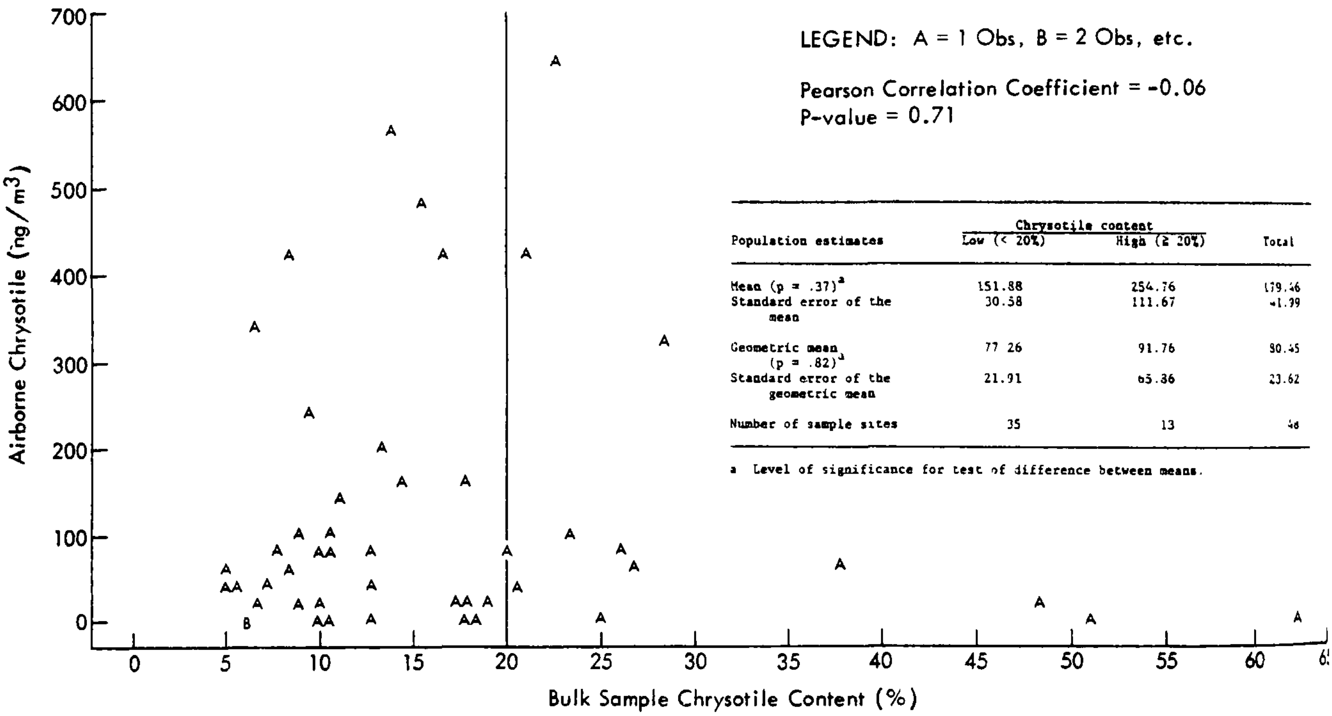
Bulk chrysotile levels are summarized in Table 24. Figure 6 displays a plot of the air level of chrysotile versus the percentage of chrysotile in asbestos-containing material for the 48 sample sites. The Pearson correlation coefficient (-0.06) is not significantly different from zero, indicating that there is no linear relationship between the bulk percentage of chrysotile and the air level of chrysotile. The table in Figure 6 shows the air levels of chrysotile (population estimates) by chrysotile content category. Chrysotile content $< 20\%$ was classified as low, $\geqq 20\%$ as high. It should be noted that the original algorithm categorized at $\leqq 50\%$ and $> 50\%$; however, for the current data, only two sites have bulk levels greater than 50% (Table 21.) The differences in means and geometric means between asbestos content categories are not significant.

Table 24. Bulk Chrysotile Content at the Asbestos-Containing Material Sites

Population estimates	Chrysotile content (%)
Mean	16
Standard error of the mean	2
Minimum	5
Median	13
Maximum	63
Number of sample sites	48

F. Other Major Components

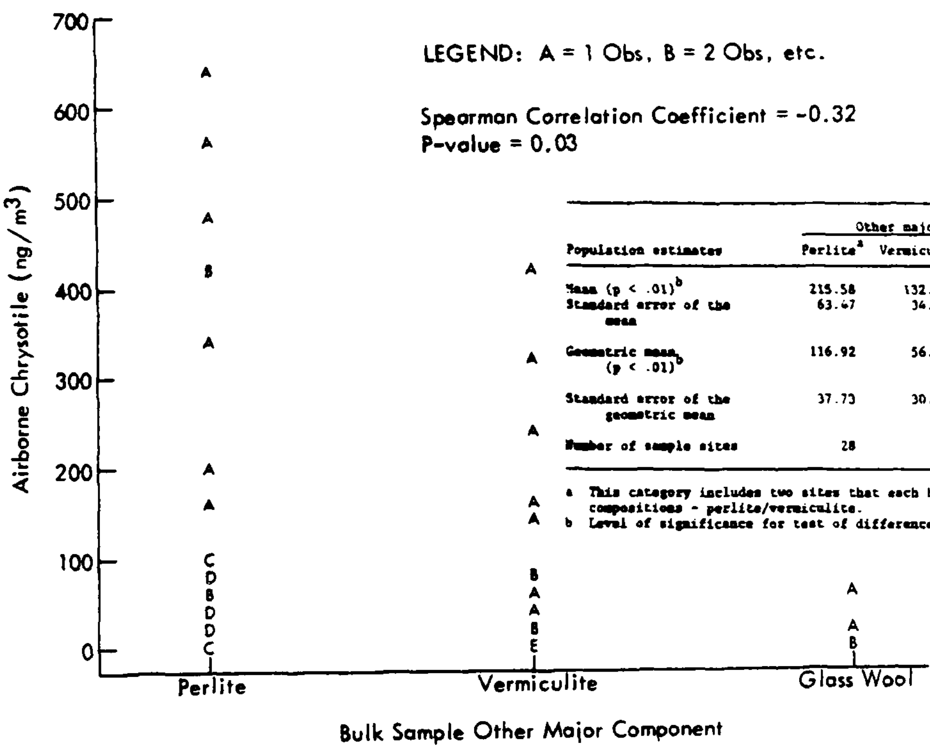
During laboratory analysis, the other major components in each bulk sample were observed--perlite, vermiculite, or glass wool. Figure 7 displays a plot of the air level of chrysotile versus the other major components in the site's asbestos-containing material, and the table in Figure 7 summarizes these data. The mean and the geometric mean air levels of chrysotile are significantly different among the other major components. The average air level of chrysotile is highest for perlite and lowest for glass wool.



Population estimates	Chrysotile content: Low (< 20%)	Chrysotile content: High (≥ 20%)	Total
Mean (p = .37)[a]	151.88	254.76	179.46
Standard error of the mean	30.58	111.67	41.99
Geometric mean (p = .82)[a]	77 26	91.76	80.45
Standard error of the geometric mean	21.91	65.36	23.62
Number of sample sites	35	13	48

a Level of significance for test of difference between means.

Figure 6. Airborne chrysotile concentration (ng/m^3) versus average bulk chrysotile percentage at 48 asbestos-containing material sites.



Population estimates	Other major component: Perlite[a]	Vermiculite	Glass wool	Total
Mean ($p < .01$)[b]	215.58	132.53	11.29	179.46
Standard error of the mean	63.47	34.82	7.89	41.99
Geometric mean ($p < .01$)[b]	116.92	56.97	3.95	80.45
Standard error of the geometric mean	37.73	30.15	3.66	23.62
Number of sample sites	28	16	4	48

a This category includes two sites that each had bulk samples of different compositions - perlite/vermiculite.
b Level of significance for test of difference between means.

Figure 7. Airborne chrysotile concentration (ng/m^3) by other major components of bulk samples at 48 asbestos-containing material sites.

Table 25 describes the percentage of chrysotile in asbestos-containing material by other major component. For sites with perlite and vermiculite, the average percentages are similar; however, the average percentage of asbestos for glass wool sites is much higher. This can be seen in Figure 8, which is a plot of air level of chrysotile versus chrysotile percentage that identifies sites according to other major components. The four glass wool sites are the sites with the highest asbestos percentage, but they have relatively low air levels of chrysotile. The friability rating given these glass wool sites was high; three sites had a rating of 3, the other a rating of 2. They had a low releasability rating, and air levels were low. Caution should be exercised in reaching conclusions about glass wool since this information is based on observations at only four sites.

Table 25. Bulk Chrysotile Content at the Asbestos-Containing Material Sites by Other Major Components

	Other major component (%)			
Population estimates	Perlite[a]	Vermiculite	Glass wool	Total (%)
Mean	14	15	50	16
Standard error	2	2	1	2
Median	13	13	51	13
Sample size	28 sites	16 sites	4 sites	48 sites

a This category includes two sites that each had bulk samples of different compositions (a perlite/vermiculite composite).

G. Releasability

The detailed microscopic examination of major nonasbestos components of the bulk samples led to the development of a new factor, referred to as releasability. This factor indicates how readily the bulk material might release the asbestos fibers into the air. During microscopic examination, the material was assigned a releasability rating between 1 (low) and 9 (high). These ratings were based upon the material's asbestos content, fiber size, brittleness of the matrix, and the apparent freedom of the individual asbestos fibers (see Section 6 for more detailed discussion of the releasability rating). The releasability rating for an asbestos-containing material site was computed by averaging (weighted) releasability ratings of bulk samples from that site. Releasability ratings were grouped into three categories: 1-4, low; 5-6, moderate; and 7-9, high.

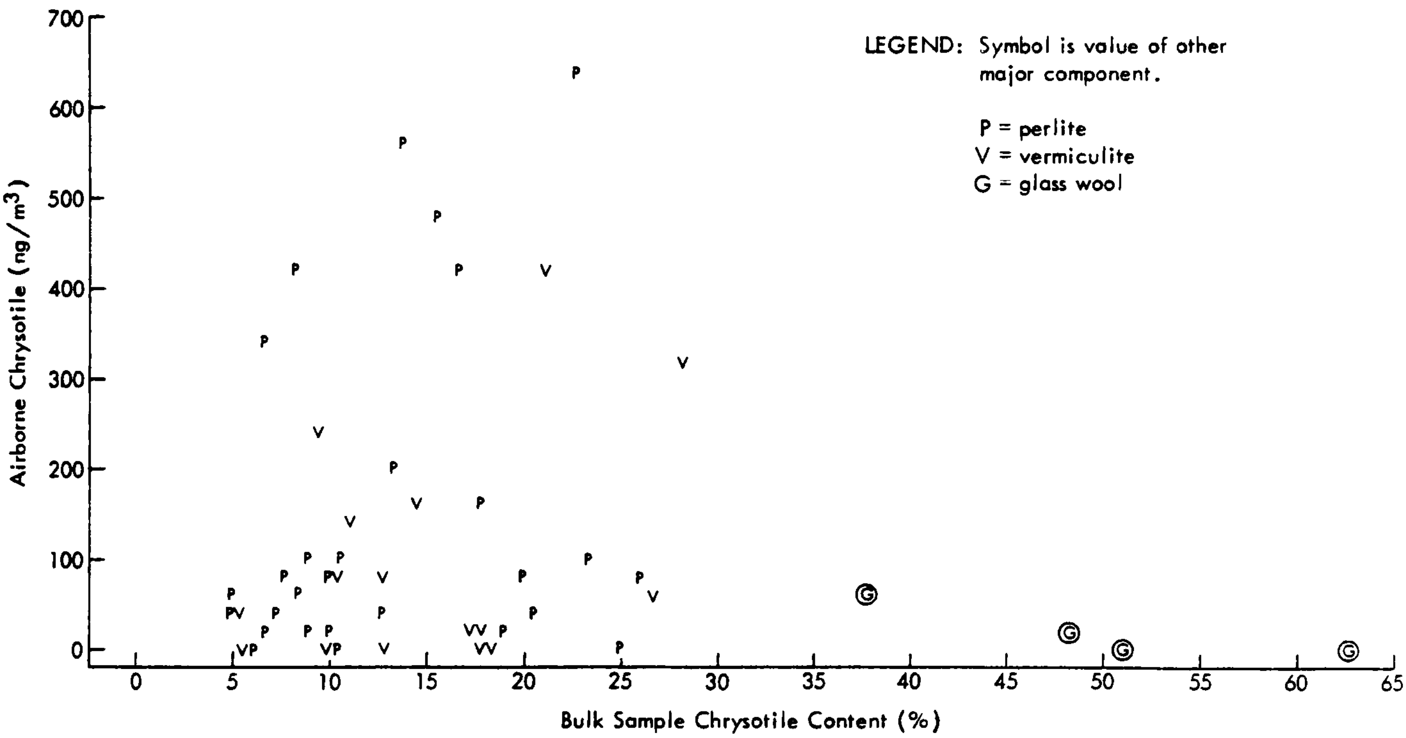


Figure 8. Airborne chrysotile concentration (ng/m^3) by average bulk chrysotile percentage and other major component at 48 asbestos-containing friable material sites.

Figure 9 displays the air levels of chrysotile by releasability category, and the table in Figure 9 summarizes these data. Both the mean and geometric mean air levels of chrysotile are significantly different among releasability categories. As releasability increases (low to moderate to high), average airborne chrysotile also increases.

Table 26 shows the distribution of asbestos-containing material sites with respect to releasability, as observed by microscopic examination of bulk samples, and friability, as observed by inspection of the sites. A tendency towards an inverse relationship between releasability and friability can be seen in Table 26. All but one of the high friability sites are low in releasability, and the majority of the low friability sites are high in releasability.

A new algorithm score was computed by substituting releasability for friability in the original score computations. Figure 10 is a plot of the air level of chrysotile versus this new score for the 48 sample sites. The correlation coefficient is .45, positive, and significantly different from zero. (Recall that the correlation coefficient using the original score is not significantly different from zero, -0.17.)

H. Other Covariables

Table 27 lists other variables about which information was collected at the asbestos-containing material sites. Room height and room volume are included in the regression analyses which follow. The other factors listed in Table 27 are not included in the analyses because little variability was exhibited by these factors across the 48 sites in the sample. When there is little variability, a meaningful assessment of the effect of different levels of the factor on airborne asbestos is not possible.

Information was collected on cleaning practices employed at the sites in the sample. Cleaning practices were divided into four categories--wet mopping only, vacuuming only, dry mopping with an oil-saturated mop, and sweeping. There is not much variability in cleaning practices; 38 of the 48 sites were dry mopped with oil. Table 28 describes the air levels of chrysotile by cleaning category. The air level means and geometric means are significantly different among cleaning categories. The average air level of chrysotile is higher for sites that were swept. Again, caution should be exercised in reaching conclusions since this information is based on only four sites that were swept. Cleaning differs from other factors considered, such as releasability or condition of the friable material, because it can be changed more easily. If sweeping does indeed contribute to an elevated level of airborne asbestos, then changing cleaning procedures seems to be a reasonable approach to reduce potential asbestos exposure rather than just using the cleaning factor in assessing the extent of potential exposure.

Population estimates	Releasability Low	Moderate	High	Total
Mean ($p < .01$)[a]	83.96	123.17	380.35	179.46
Standard error of the mean	24.52	32.29	82.15	41.99
Geometric mean ($p < .01$)[a]	31.79	74.19	280.46	80.45
Standard error of the geometric mean	18.03	25.56	84.44	23.62
Number of sample sites	19	17	12	48

a Level of significance for test of difference between means.

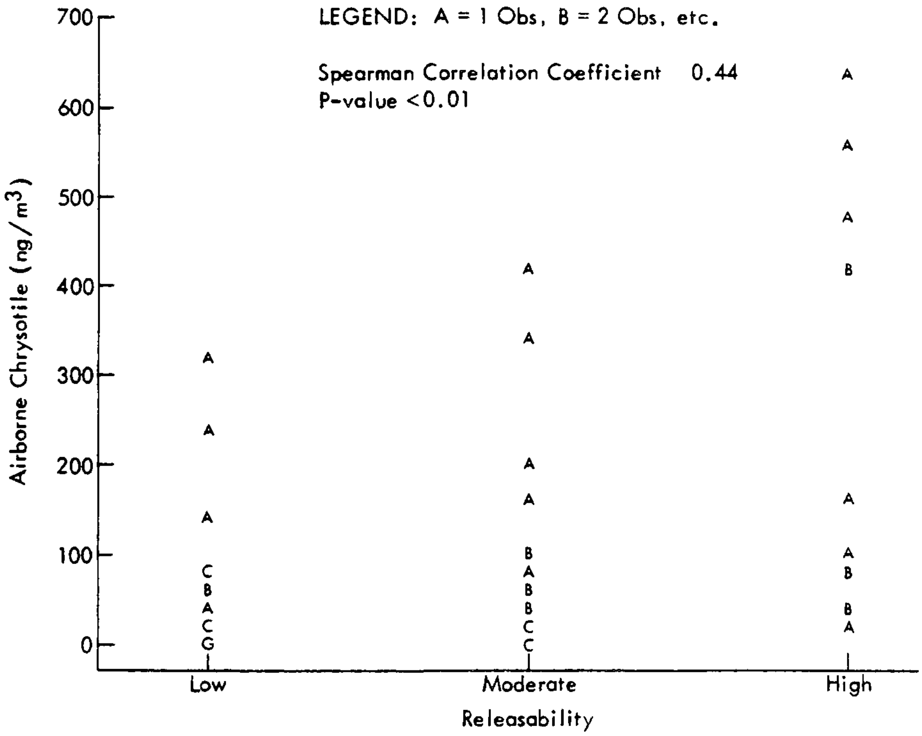


Figure 9. Airborne chrysotile concentration (ng/m^3) versus releasability categories at 48 asbestos-containing material sites.

Table 26. Distribution of the Asbestos-Containing Material Sites with Respect to Friability and Releasability (Population Estimates)

Releasability	Friability			Total
	Low	Moderate	High	
Low				
Percentage of sites	5	16	12	33
Standard error (%)	4	6	7	8
Number of sample sites	2	11	6	19
Moderate				
Percentage of sites	5	34	< 1	40
Standard error (%)	5	9	< 1	9
Number of sample sites	2	14	1	17
High				
Percentage of sites	16	11	0	27
Standard error (%)	7	7	0	10
Number of sample sites	8	4	0	12
Total				
Percentage of sites	26	62	12	100
Standard error (%)	10	12	7	0
Number of sample sites	12	29	7	48

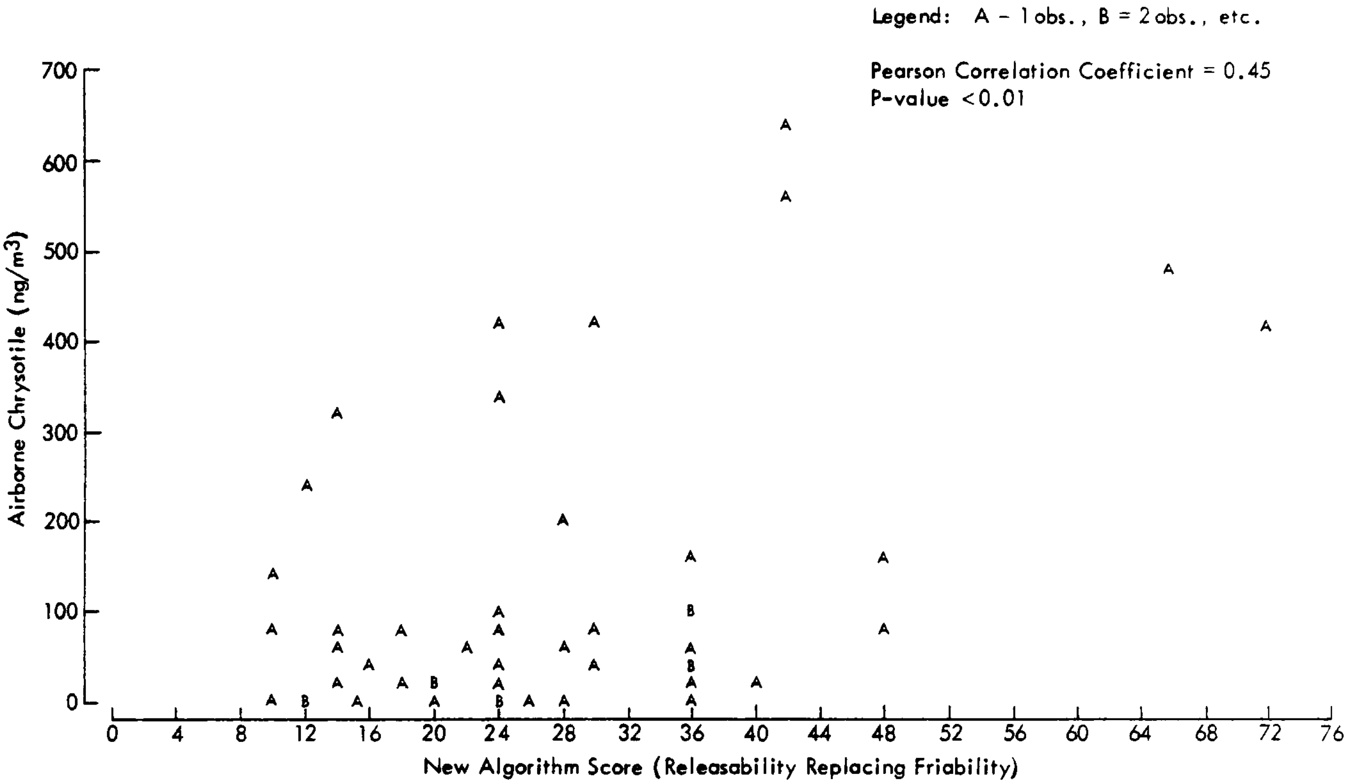


Figure 10. Plot of airborne chrysotile concentration (ng/m^3) versus new score (releasability substituted for friability) for asbestos-containing material friable sites.

Table 27. Candidate Covariables

Variable	Missing data N[a]	Missing data %	Mean	Std. deviation	Coeff. of variation[b]
Temperature (N = 36)	12	(25.0)	24.8°C	1.6°C	0.06
Humidity (N = 36)	12	(25.0)	64.2%	7.4%	0.12
Sampling height (N = 44)	4	(8.3)	1.4 m	0.4 m	0.29
Room height (N = 48)	0	NA*	3.5 m	1.47 m	0.42
Room volume (N = 48)	0	NA	792 m^3	1,271 m^3	1.60
Air conditioning status (N = 44)	4	(8.3)		90% operating	
Friable material location (N = 48)	0	NA		98% on ceilings	
Floor carpeting (N = 48)	0	NA		94% uncarpeted	
Tile floor (N = 48)	0	NA		92% had tile floor	
Wood floor (N = 48)	0	NA		100% did not have	
Suspended ceilings (N = 48)	0	NA		100% did not have	

a Number of sample sites.

b Coefficient of variation = $\frac{\text{std. deviation}}{\text{mean}}$

* NA = not applicable.

Table 28. Airborne Chrysotile Concentration (ng/m^3) for Asbestos-containing Friable Material Sites by Cleaning Category

Population estimates	Cleaning category[a] 1	2	3	4	Total
Mean ($p < .01$)[b]	19.28	39.83	159.96	368.41	179.46
Standard error of the mean	4.36	13.52	31.71	163.64	41.99
Geometric mean ($p = .01$)[b]	16.64	32.78	76.48	182.09	80.45
Standard error of the geometric mean	6.00	10.81	23.24	151.97	23.62
Number of sample sites	3	3	38	4	48

a Cleaning category: 1 = wet mopped only; 2 = vacuumed only; 3 = dry mopped with oil-saturated mop; 4 = swept (includes two sites that were swept and also dry mopped with oil-saturated mop).
b Level of significance for test of difference between means.

I. Long-Term Variability

To examine the variability of air levels in chrysotile over time, air sampling was conducted at 3 of the 48 asbestos-containing material sites for three consecutive weeks, instead of just 1 week. Air sampling was also conducted for 3 weeks at the control and ambient sites corresponding to these asbestos-containing material sites. Substantial variability over time was observed. Caution should be employed in interpreting the data because they are based upon a small number of sites. The long-term sampling data are listed in Table 29.

For the long-term site selected from Group 1 (large student activity areas), the following air levels of chrysotile are observed: week 1, 10.00 ng/m^3; week 2, 0.76 ng/m^3; and week 3, 1.50 ng/m^3. The average over 3 weeks at this site is 4.09 ng/m^3, and the standard deviation is 5.13 ng/m^3, resulting in a coefficient of variation equal to 1.25. This variability over time at one site can be compared to the variability in air levels of chrysotile among the different sites in Group 1; the coefficients of variation, 1.25 and 1.17, are very similar. The coefficient of variation over all asbestos-containing material sites is 1.06. Comparisons like this can be made using the other two long-term sites as well as the long-term controls and ambients.

It follows that variability over time at the same site appears to be comparable to variability among different sites within the various groups. This

Table 29. Variability of Airborne Chrysotile Concentration (ng/m^3) over Time at Three Asbestos-containing Friable Material Sites and the Corresponding Control and Ambient Sites

	School 10 Swimming Pool Room (Group 1[a])			School 3 Classroom 204 (Group 2[b])			School 2 Classroom 221 (Group 3[c])		
	Site	Control	Ambient	Site	Control	Ambient	Site	Control	Ambient
Airborne Chrysotile (ng/m^3)									
Week 1	10.00	72.90	0.55	105.00	166.00	2.70	32.30	3.00	4.10
Week 2	0.76	50.30	10.80	27.50	14.60	17.60	61.20	2.60	1.30
Week 3	1.50	73.40	1.10	6.17	45.50	0.00	6.80	0.00	8.88
Mean	4.09	65.53	4.15	46.22	75.37	6.77	33.43	1.87	4.76
Standard deviation	5.13	13.19	5.77	52.01	80.00	9.48	27.22	1.63	3.83
Coefficient of variation[d]	1.25	0.20	1.39	1.13	1.06	1.40	0.81	0.87	0.80

Variability of Airborne Chrysotile Concentration (ng/m^3) for the Asbestos-containing Friable Material Sites by Group[a]

Population estimates	Group 1[a]	Group 2[b]	Group 3[c]	Total
Mean	14.80	209.32	186.78	179.46
Standard error of the mean	8.16	45.11	53.80	41.99
Standard deviation	17.31	130.22	204.29	190.86
Coefficient of variation[d]	1.17	0.62	1.09	1.06
Median	8.58	196.00	92.70	92.70
Number of sample sites	9	10	29	48

a Group 1: large student activity areas.

b Group 2: classrooms and corridors with high friability, or a combination of high asbestos content and moderate friability (according to the school district rating).

c Group 3: classrooms and corridors with low friability, a combination of low asbestos content and moderate friability, or a combination of unknown asbestos content and moderate friability (according to the school district rating).

d Coefficient of variation = standard deviation/mean.

result is limited by the small number of sites on which it is based as well as by the time period of only 3 weeks.

III. REGRESSION ANALYSES

The previous analyses focused upon the relationship between airborne chrysotile and a number of possible predictors of airborne levels, but only two variables were considered in each separate analysis--the dependent variable (airborne chrysotile) and one predictor (e.g., material condition, releasability, or the algorithm score). The analyses described in this subsection, on the other hand, focus on the relationship between airborne chrysotile and a set of possible predictors or independent variables. The reason for these multivariable analyses is the recognition that the candidate predictors are theoretically and empirically related to one another, and that predictions can generally be improved if multiple variables are considered simultaneously.

The continuous nature of airborne chrysotile measurements suggested that multiple linear regression could be used to construct a series of models that might be reasonably predictive of the chrysotile level in sites with specified characteristics; thus, standard multiple regression procedures were generally employed. However, two preliminary decisions had to be made to define the boundaries of the analytical problem. Specifically, the pool of candidate predictors had to be defined, and transformations of the dependent variable had to be considered.

The candidate predictors placed in the independent variable pool included material condition, accessibility, air stream status, water damage, activity, friability, average bulk sample chrysotile percentage, releasability, room volume, room height, and typical cleaning practices. The "exposed surface" variable was excluded from the set of candidate predictors because all 48 asbestos-containing material sites were 100% exposed. Releasability and the cleaning practices variable were included because previous bivariate analyses suggested that these factors are somewhat predictive of airborne chrysotile levels (see Figure 9 and Table 28). Room volume and height were included because of special interest in airborne chrysotile levels in rooms with large volumes and/or high ceilings. Specifically, there was the issue of the impact of room volume or ceiling height upon the relationship between the algorithm factors and airborne chrysotile levels. The average bulk sample (chrysotile) percentage variable was included instead of the coded (grouped) bulk sample variable because there may be some loss of useful information when the estimated percentage of chrysotile in the friable material is replaced by a code representing a crude range of percentages. Variables such as temperature, humidity, air sampling height, and type of flooring were not included in the independent variable pool because they had little variation across the 48 asbestos-containing friable material sites (see Table 27).

Transformations of the dependent variable had to be considered because the data suggested that the airborne chrysotile distribution in the study area was positively skewed. A transformation of the general form $\log_e$ (airborne chrysotile level + k), where k is a constant, was an obvious choice because of the positive skew, but the choice for k was more arbitrary. A value of

1.0 ng/m^3 for k was assumed because the available data suggest that the background level of airborne chrysotile in the United States is less than 10 ng/m^3 (Nicholson et al. 1978).

The next issue after specifying the independent variable pool and the dependent variable transformation was selecting a procedure for identifying a simple predictive regression model. A number of stepwise model building procedures are available, but many focus exclusively upon the "statistical significance" of predictor contributions to the regression model. Thus, statistical considerations may produce a model which does not fit well with substantive or theoretical considerations. To minimize this possibility, a two-stage model selection procedure was used. During the first stage, R^2 statistics for all possible models of a given size were examined. (The R^2 statistic ranges between 0.00 and 1.00 and indicates the proportion of the observed airborne chrysotile variation which is explained by the independent variables.) In this way, a number of better predicting models were identified. During the second stage, the algebraic signs and the p-values for model coefficients were examined. Emphasis focused upon identifying predictive models with the expected coefficient sign (positive and negative) and small p-values. Thus, the identification of a "best" model was based upon statistical and substantive considerations.

Table 30 displays a summary of unweighted regression models. The unweighted models are based upon relationships present in the data from the 48 selected sites. Weighted models should be used when the analytical focus is shifted from the 48 selected sites to the target population of sites in the study area. Inspection of the R^2 statistics associated with the one-variable models suggests that releasability is the best single predictor of airborne chrysotile. Specifically, releasability accounts for approximately 22% of the airborne chrysotile variation. Inspection of the two-variable models and the correponding R^2 statistics reveals that the addition of the cleaning variable (or the room volume variable) explains an additional 4% of the airborne chrysotile variation. Inspection of the three-variable models suggests that the addition of water damage to the model with releasability and the cleaning variable accounts for another 5% of the airborne chrysotile variation. However, the addition of a fourth variable to the model increases the R^2 statistic by less than 5%. This leveling off of the R^2 statistic indicates that most of the statistically useful information contained in the independent variable pool has been accounted for by the variables releasability, cleaning, and water damage (or room volume). These variables account for only one-third of the observed airborne chrysotile variation.

Consideration of other models underlines the importance of releasability from a predictive perspective. Specifically, a model based upon seven of the original algorithm variables (exposed surfaces excluded) yields an R^2 statistic (R^2 = .19) less than that yielded by releasability alone (R^2 = .22). Moreover, the substitution of releasability for friability increases the R^2 associated with the algorithm-based model from .19 to .31. This latter model is no less predictive than the optimal three-variable model identified above (R^2 = .31).

Table 30. Summary of Unweighted Regression Models: Relationship of Surrogate Measurements to Airborne Chrysotile Concentration

Dependent variable = Log (ng/m^3 airborne chrysotile + 1.0)

Independent variable	R^2 [a]
(1) One-variable models	
Activity	< 0.01
Condition	< 0.01
Air stream status	< 0.01
Accessibility	0.03
Water damage	0.04
Friability	0.06
Chrysotile content (%)	0.06
Cleaning	0.08
Room height	0.11
Room volume	0.13
Releasability	0.22
(2) Two-variable models with highest R^2s	
Releasability, water damage	0.24
Releasability, cleaning	0.26
Releasability, chrysotile content (%)	0.26
Releasability, room volume	0.27
(3) Three-variable models with highest R^2s	
Releasability, water damage, chrysotile content (%)	0.29
Releasability, cleaning, chrysotile content (%)	0.29
Releasability, room volume, water damage	0.30
Releasability, cleaning, water damage	0.31
(4) Four-variable models with highest R^2s	
Releasability, cleaning, water damage, air stream status	0.32
Releasability, cleaning, water damage, room height	0.33
Releasability, cleaning, water damage, room volume	0.33
Releasability, cleaning, water damage, chrysotile content (%)	0.35
(5) Original algorithm factors (% chrysotile content) $R^2 = 0.19$	
(6) Original algorithm factors (% chrysotile content), with releasability replacing friability $R^2 = 0.31$	

a Proportion of airborne chrysotile variation explained by the independent variables.

Table 31 displays the coefficient signs and p-values associated with six unweighted regression models. Model I is based upon the original algorithm factors and was mentioned above. Model II is similar except that releasability was substituted for friability. Model III is the optimal three-variable model, while Models IV and V are two of the more predictive four-variable models. Model VI is a variant of Model V.

An important aspect of Models I and II in Table 31 is that four of the seven predictors in each model have negative coefficients, and only one of the coefficients in Model II is significantly different from zero. Present theory (and speculation) concerning the determinants of airborne chrysotile predicts that each of these factors should be positively related to the dependent variable. Thus, Model III is much more satisfactory because all the predictors have positive coefficients and all of the coefficients are significantly different from zero ($p = .10$ level).

Table 32 displays the coefficients and p-values associated with six weighted regression models. The weighted models take into account the probability sample design used in site selection and are applicable to the target population of sites in the study area. Because the 48 sample sites were not selected with equal probabilities, sampling weights were used to adjust information to facilitate valid statistical inferences from the 48 sites to the study area. (Recall that the study area consists of all school district student activity areas with material known to or suspected of containing asbestos.) The models presented in Table 32 are similar to the models presented in Table 31 except that the estimate of each model coefficient and its standard error have been slightly altered by the weighted calculations. Model-specific comparisons between Tables 31 and 32 reveal that in each case the weighted regression model has a slightly larger R^2 statistic. This phenomenon highlights the fact that the models fit better in the actual study area than in a hypothetical study area with a distribution of sites directly proportional to the distribution of sample sites.

The smaller R^2 statistic associated with Model I in Table 32 argues against the use of this set of predictors based upon the original algorithm variables. Thus, attention should focus upon one of the remaining models which include releasability. Model II should also be rejected because the majority of the coefficient estimates are not significantly different from zero and several have negative signs. Model III is a strong candidate for the most reasonable model because all three coefficients are positive. The remaining models in Table 32 have slightly larger R^2 statistics, but each has a negative coefficient with a large p-value.

Table 31. Unweighted Regression Models: Relationship of Surrogate Measurements to Airborne Chrysotile Concentration

Dependent variable = Log (ng/m^3 airborne chrysotile + 1.0)

Independent variable	Sign of coefficient	Probability value
Model I. Original algorithm factors (R^2 = 0.19[a])		
Condition	-	0.37
Accessibility	-	0.46
Air stream status	+	0.75
Water damage	+	0.12
Activity	+	0.53
Friability	-	0.27
Chrysotile content (%)	-	0.12
Model II. Original algorithm factors, with releasability replacing friability (R^2 = 0.31)		
Condition	-	0.76
Accessibility	-	0.43
Air stream status	-	0.99
Water damage	+	0.20
Activity	+	0.73
Releasability	+	< 0.01
Chrysotile content (%)	-	0.12
Model III. Releasability, cleaning, and water damage (R^2 = 0.31)		
Releasability	+	< 0.01
Cleaning	+	0.05
Water damage	+	0.08
Model IV. Releasability, cleaning, water damage, and air stream status (R^2 = 0.32)		
Releasability	+	< 0.01
Cleaning	+	0.04
Water damage	+	0.06
Air stream status	-	0.43
Model V. Releasability, cleaning, water damage, and chrysotile content (%) (R^2 = 0.35)		
Releasability	+	< 0.01
Cleaning	+	0.06
Water damage	+	0.06
Chrysotile content (%)	-	0.10
Model VI. Releasability, cleaning, water damage, and chrysotile content category (Category 1 is < 20%, Category 2 is ≧ 20%) (R^2 = 0.31)		
Releasability	+	< 0.01
Cleaning	+	0.05
Water damage	+	0.08
Chrysotile content category	-	0.71

a Proportion of airborne chrysotile variation explained by the independent variables.

Table 32. Weighted Survey Regression: Relationship of Surrogate Measurements to Airborne Chrysotile Concentration

Dependent variable = Log (ng/m^3 airborne chrysotile + 1.0)

Independent variable	Sign of coefficient	Probability value
Model I. Original algorithm factors (R^2 = 0.22[a])		
Condition	-	< 0.01
Accessibility	-	0.88
Air stream status	+	0.94
Water damage	+	0.10
Activity	+	0.52
Friability	-	0.85
Chrysotile content (%)	-	0.22
Model II. Original algorithm factors, with releasability replacing friability (R^2 = 0.38)		
Condition	-	0.07
Accessibility	-	0.79
Air stream status	+	0.97
Water damage	+	0.24
Activity	+	0.69
Releasability	+	0.01
Chrysotile content (%)	-	0.15
Model III. Releasability, cleaning, and water damage (R^2 = 0.32)		
Releasability	+	< 0.01
Cleaning	+	0.13
Water damage	+	0.28
Model IV. Releasability, cleaning, water damage, and air stream status (R^2 = 0.33)		
Releasability	+	< 0.01
Cleaning	+	0.12
Water damage	+	0.32
Air stream status	-	0.67
Model V. Releasability, cleaning, water damage, and chrysotile content (%) (R^2 = 0.36)		
Releasability	+	< 0.01
Cleaning	+	0.21
Water damage	+	0.31
Chrysotile content (%)	-	0.15
Model VI. Releasability, cleaning, water damage, and chrysotile content category (Category 1 is < 20%, Category 2 is ≧ 20%) (R^2 = 0.33)		
Releasability	+	< 0.01
Cleaning	+	0.16
Water damage	+	0.30
Chrysotile content category	-	0.67

a Proportion of airborne chrysotile variation explained by the independent variables.

Figures 11 through 13 can be used to obtain a more intuitive appreciation of the predictive character of regression models with R^2 statistics less than .500. Figure 11 displays a plot of the observed airborne chrysotile values (on a log scale) versus the predicted values obtained from an unweighted regression model based upon releasability and six of the original algorithm factors (see Model II, Table 31). (Figure 5 displays a plot of airborne chrysotile values versus algorithm score values.) If the model were perfectly predictive, the R^2 statistic would be 1.00 and all of the points in Figure 11 would fall along a straight line. The scatter of the points about this straight line represents airborne chrysotile variation which is not statistically explained by the seven independent variables. Figure 12 is identical to Figure 11, except that the observed and the predicted values have not been transformed. Figure 13 displays a similar plot of (logged) observed versus predicted airborne chrysotile values except that the regression model (see Model III, Table 31) contains only three independent variables (releasability, cleaning, and water damage).

Regardless of which of the better predicting models is selected as most reasonable, it is clear from the R^2 statistics in Table 32 and the plots in Figures 11 and 13 that only moderately accurate predictors of airborne chrysotile have been identified. A highly satisfactory set of predictors should have an R^2 statistic of at least .80, and the model coefficients should have algebraic signs consistent with physical theory.

In summary, the data suggested that the four-variable models were not meaningfully superior to the three-variable model based upon releasability, cleaning, and water damage. However, the inclusion of a "cleaning" variable in an exposure assessment algorithm may create additional measurement problems because school personnel have to be queried to obtain the relevant information. There was some interest, therefore, in optimal models based upon an independent variable pool which did not contain the cleaning variable. Table 33 presents a series of optimal unweighted regression models based upon a variable pool without cleaning. The best two-, three-, and four-variable models are displayed.

Inspection of Table 33 reveals that the optimal three-variable model from this pool includes releasability, room volume, and water damage. Thus, the exclusion of the cleaning variable allows room volume into the three-variable model, while the inclusion of a fourth variable does not appreciably increase the R^2 statistic. Table 34 presents additional characteristics of the optimal three-variable model obtained when cleaning is excluded. Specifically, it is of interest that releasability and water damage have positive coefficients, while the room volume coefficient is negative. After adjusting for the effects of releasability and water damage, larger sites (rooms) appear to have lower airborne chrysotile concentrations. A slightly negative room volume/airborne chrysotile relationship was first observed in the bivariate analyses.

Overall, two optimal three-variable models were identified and judged to be reasonable taking statistical and substantive issues into consideration. The first model is based upon releasability, water damage, and cleaning, and the second is based upon releasability, water damage, and room volume.

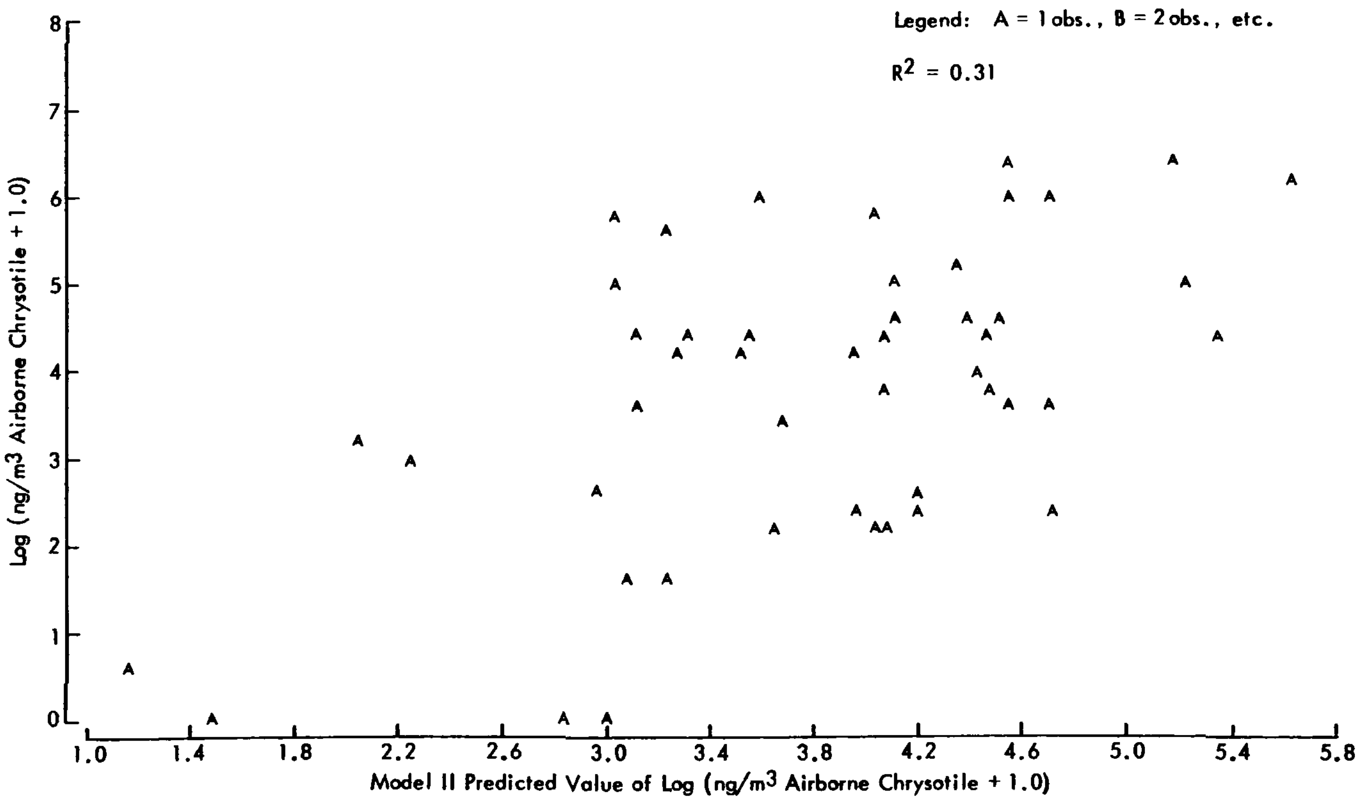


Figure 11. Log (ng/m^3 airborne chrysotile + 1.0) versus the predicted value from Model II (original algorithm factors, with releasability replacing friability) for asbestos-containing friable material sites.

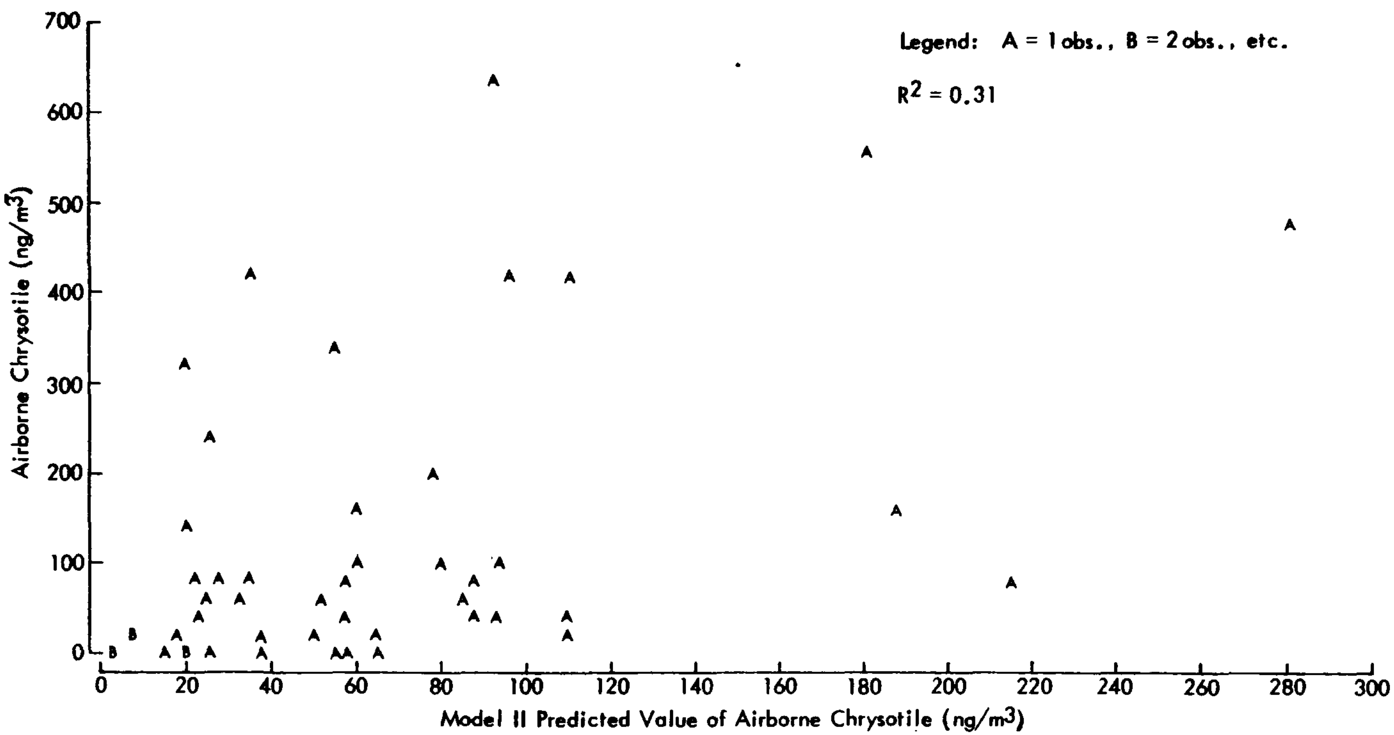


Figure 12. Airborne chrysotile concentration (ng/m^3) versus the predicted value from Model II (original algorithm factors, with releasability replacing friability) for asbestos-containing friable material sites.

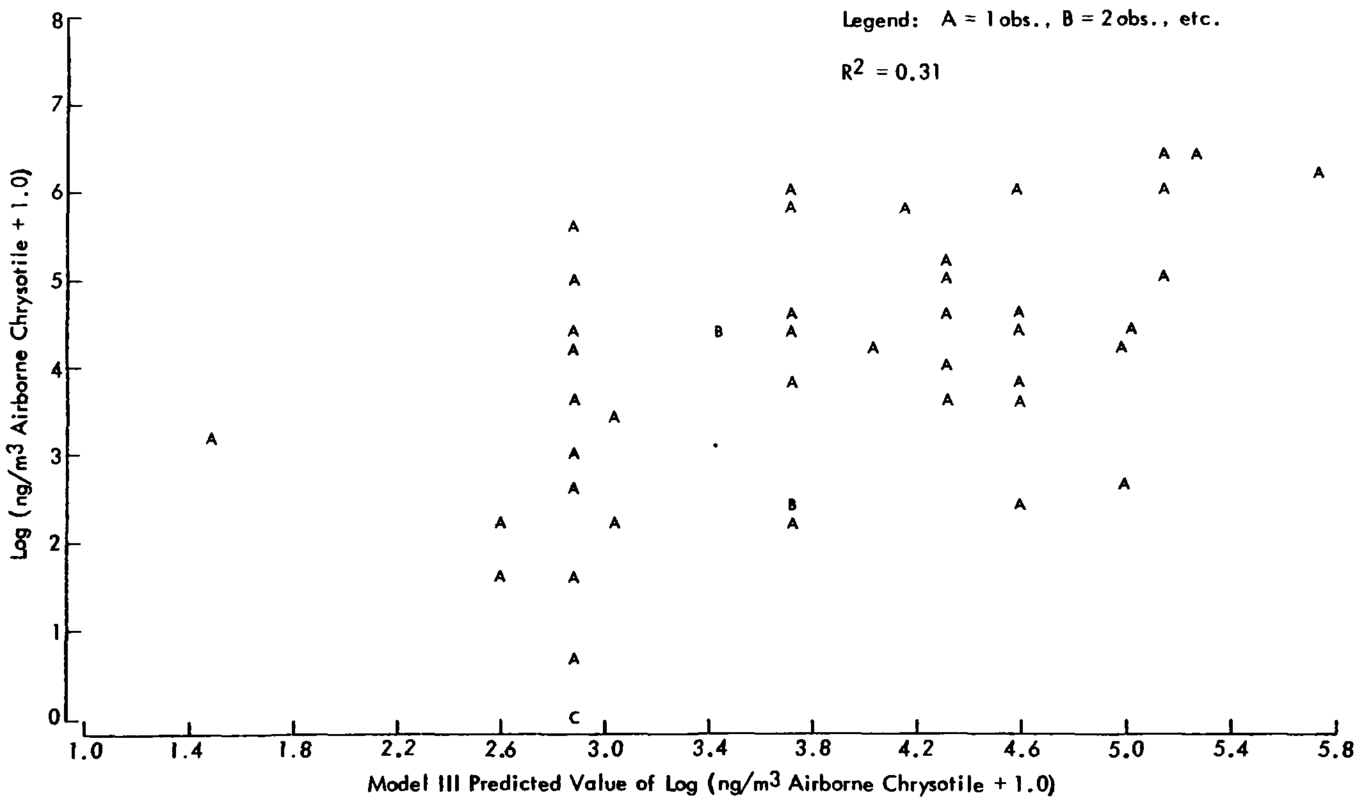


Figure 13. Log (ng/m^3 airborne chrysotile + 1.0) versus the predicted value from Model III (releasability, cleaning, and water damage) for asbestos-containing friable material sites.

Table 33. Summary of Unweighted Regression Models: Relationship of Surrogate Measurements (Excluding Cleaning Practices) to Airborne Chrysotile Concentration

Dependent variable = Log (ng/m^3 airborne chrysotile + 1.0)

Independent variable	R^2 [a]
(1) Two-variable models with highest R^2s	
Releasability, room height	0.24
Releasability, water damage	0.24
Releasability, chrysotile content (%)	0.26
Releasability, room volume	0.27
(3) Three-variable models with highest R^2s	
Releasability, room volume, chrysotile content (%)	0.28
Releasability, room volume, activity	0.29
Releasability, water damage, chrysotile content (%)	0.29
Releasability, room volume, water damage	0.30
(4) Four-variable models with highest R^2s	
Releasability, room volume, water damage, friability	0.31
Releasability, room volume, water damage, accessibility	0.31
Releasability, room volume, water damage, activity	0.31
Releasability, room volume, water damage, chrysotile content (%)	0.32

a Proportion of airborne chrysotile variation explained by the independent variables.

Table 34. Three-Variable Regression Models: Relationship of Surrogate Measurements (Excluding Cleaning Practices) to Airborne Chrysotile Concentration

Dependent variable = Log (ng/m^3 airborne chrysotile + 1.0)

Independent variable	Sign of coefficient	Probability value
Optimal unweighted three-variable model (R^2 = 0.30[a])		
Releasability	+	< 0.01
Room volume	-	0.06
Water damage	+	0.16
Corresponding weighted three-variable model (R^2 = 0.35)		
Releasability	+	0.02
Room volume	-	0.03
Water damage	+	0.46

a Proportion of airborne chrysotile variation explained by the independent variables.

The first model is only slightly more predictive of airborne chrysotile levels, but the second may be more useful in abatement programs if accurate data on cleaning practices are not easily obtainable. The reliability and generalizability of releasability measurements should be documented in additional studies, and other predictors of airborne chrysotile levels should be identified. Both of the optimal three-variable models explain less than half of the observed airborne chrysotile variation.

IV. ALTERNATIVE CLASSIFICATION ANALYSES

The true airborne chrysotile level at a site with specified characteristics can be estimated if a satisfactory regression model has been developed and the pertinent independent variables have been accurately measured. However, an estimate of the true airborne chrysotile level at a specified site may be of less interest than a prediction of whether the airborne chrysotile level at a specified site is higher or lower than some specified reference level. That is, when abatement decisions are made, a specific abatement procedure is either followed, or it is not, regardless of the exact airborne asbestos level at the site. In essence, the prediction or identification of sites with high or low airborne chrysotile levels is a classification problem, and several types of classification analyses were completed. Different definitions of high or low airborne chrysotile levels were used in the classification analyses.

Table 35 summarizes the results from a preliminary two-group discriminant analysis. The dependent variable was an airborne chrysotile dichotomy created by using the unweighted median (68.6 ng/m^3) as a cut point. The independent variables were the seven original algorithm factors (exposed surfaces excluded). According to Table 35 the linear discriminant function correctly classified 60% of the observations. However, the performance of all two-group discriminant models (and the other classification analyses) should be compared with performance of an unbiased "coin" which could correctly classify 50% of the available observations.

Table 36 presents the results from a series of discriminant analyses similar to the one displayed in Table 35. Comparisons between the analyses in Table 36 emphasize the effect of different airborne chrysotile cut points upon two statistics of interest--the percentage of all observations correctly classified, and the percentage of observations above the cut point correctly classified. The latter statistic indicates the sensitivity of the classification. Table 36 demonstrates that the sensitivity of the classification is decreased when the cut point is increased. Table 36 also suggests that total number of classification errors can be reduced by selecting a cut point higher or lower than 68.6 ng/m^3, but the data do not suggest whether 11.1 ng/m^3 (25th percentile) or 149.5 ng/m^3 (75th percentile) is preferable. Of course, substantive issues such as the ambient level of airborne chrysotile could be addressed when the optimal cut point is designated.

Comparisons between Table 36 analyses also emphasize the effect of different models upon the statistics of interest. Specifically, the substitution of releasability ratings for friability ratings decreases the impact of a

Table 35. Predicting Low/High Airborne Chrysotile Concentration with a Discriminant Function[a] Based upon Seven Original Algorithm Factors[b]

Distribution of the 48 Asbestos-containing Friable Material Sites: Observed Airborne Chrysotile Concentration Versus Predicted

Observed airborne chrysotile concentration (ng/m^3)	Predicted by discriminant function Low ($\leqq$ 68.6)	High (> 68.6)	Total
Low ($\leqq$ 68.6[c])	16	8	24
High (> 68.6)	11	13	24
Total	27	21	48

% Correct = 29/48 = 60.4%
Sensitivity = 13/24 = 54.2%

a Discriminant analysis with pooled covariance matrix and prior probabilities proportional to sample sizes.
b The factor exposure was not included because of zero variability. The original algorithm categorization of bulk sample chrysotile content was used.
c 68.6 ng/m^3 = 50th percentile for the 48 asbestos-containing friable material sites.

Table 36. Summary of Discriminant Analyses

Airborne chrysotile concentration cut point	Independent variables	Statistics: % Correct	Statistics: Sensitivity (%)
11.1 ng/m^3 (25th %)[a]	7 algorithm factors[b]	79.2	100.0
68.6 ng/m^3 (50th %)	7 algorithm factors	60.4	54.2
149.5 ng/m^3 (75th %)	7 algorithm factors	79.2	25.0
11.1 ng/m^3 (25th %)	Releasability rank and 6 algorithm factors[c]	79.2	100.0
68.6 ng/m^3 (50th %)	Releasability rank and 6 algorithm factors	64.6	62.5
149.5 ng/m^3 (75th %)	Releasability rank and 6 algorithm factors	81.2	41.7

a Percentile of the observed airborne chrysotile concentration distribution for the 48 asbestos-containing friable material sites.

b The factor exposure was not included because of zero variability. The original algorithm categorization of bulk sample chrysotile content was used.

c The factor friability was replaced by the releasability rank (possible values 1-9) determined from bulk sample inspection.

changing cut point upon the sensitivity of the classification. When the original seven algorithm factors are included in the discriminant model, the sensitivity of the classification decreases to 54.2% and 25% when the two higher cut points are used. When releasability is substituted for friability, the sensitivity of the classification decreases to 62.5% and 41.7%, respectively. Substitution of the releasability ratings also decreases the total number of classification errors when the higher cut points are used.

Table 37 summarizes an attempt at predicting high and low airborne chrysotile sites with an algorithm score dichotomy. The algorithm score dichotomy was based upon the median consensus score (28), while the airborne chrysotile dichotomy was based upon the 50th percentile (68.6 ng/m^3) and the 75th percentile (149.5 ng/m^3). Inspection of the percentages of observations correctly classified in Table 37 suggests that all the previous discriminant analyses outperformed the simple algorithm score dichotomy.

Table 38 summarizes an attempt at predicting high/low airborne chrysotile sites with a releasability dichotomy. High releasability was defined as a rating greater than 6, while the airborne chrysotile dichotomy was based upon either the 50th or the 75th percentile. Inspection of the percentages of observations correctly classified in Table 38 suggests that the releasability dichotomy also outperformed the algorithm score dichotomy. Yet two of the discriminant models in Table 36 performed slightly better.

Tables 39 and 40 (and G-1 in Appendix G) summarize various attempts at predicting high/low airborne chrysotile sites with several regression-based dichotomies. The regression models used in these analyses correspond to some of the unweighted models presented in the previous section. The motivation for these analyses was to demonstrate how regression models can be used to classify sites with respect to a designated cut point.

Tables 41 through 45 (and G-2 through G-6) summarize various attempts at predicting high/low airborne chrysotile sites with decision trees based upon some of the original algorithm factors and releasability. Parallel analyses using either the 50th (Tables G-2 to G-6) or the 75th (Tables 41 to 45) airborne chrysotile percentile to identify high/low airborne chrysotile sites were completed. Table 41 (and G-2) is concerned with the original decision tree based upon exposed surfaces, material condition, accessibility, and friability, while Table 42 (and G-3) is concerned with a tree based upon releasability and water damage. Table 43 (and G-4) examines a tree based upon releasability and airstream status, while Table 44 (and G-5) examines a tree based upon releasability and the bulk chrysotile percentage. Table 45 (and G-6) summarizes the performance of a more complex tree based upon releasability, water damage (or material condition), and airstream status.

Table 37. Predicting Low/High Airborne Chrysotile Concentration with the Algorithm Score[a] Dichotomy

Distribution of the 48 Asbestos-containing Friable Material Sites: Observed Airborne Chrysotile Concentration Versus Predicted

Observed airborne chrysotile concentration (ng/m^3)	Predicted by score dichotomy: Low (Score ≦ 28[b])	Predicted by score dichotomy: High (Score > 28)	Total
Low (≦ 68.6[c])	13	11	24
High (> 68.6)	16	8	24
Total	29	19	48

% Correct = 21/48 = 43.8%
Sensitivity = 8/24 = 33.3%

Observed airborne chrysotile concentration (ng/m^3)	Low (Score ≦ 28)	High (Score > 28)	Total
Low (≦ 149.5)	20	16	36
High (> 149.5)	9	3	12
Total	29	19	48

% Correct = 23/48 = 47.9%
Sensitivity = 3/12 = 25.0%

a Consensus score based upon the original eight factors.
b 28 = 50th percentile (population estimate) of the algorithm scores for asbestos-containing friable material sites.
c 68.6 ng/m^3 = 50th percentile for the 48 asbestos-containing friable material sites.
d 149.5 ng/m^3 = 75th percentile for the 48 asbestos-containing friable material sites.

Table 38. Predicting Low/High Airborne Chrysotile Concentration with a Releasability Dichotomy

Distribution of the 48 Asbestos-containing Friable Material Sites: Observed Airborne Chrysotile Concentration Versus Predicted

Observed airborne chrysotile concentration (ng/m^3)	Predicted by releasability rank: Low (Ranks 1-6)	Predicted by releasability rank: High (Ranks 7-9)	Total
Low (≦ 68.6[a])	21	3	24
High (> 68.6)	15	9	24
Total	36	12	48

% Correct = 30/48 = 62.5%
Sensitivity = 9/24 = 37.5%

Observed airborne chrysotile concentration (ng/m^3)	Predicted by releasability rank: Low (Ranks 1-6)	Predicted by releasability rank: High (Ranks 7-9)	Total
Low (≦ 149.5[b])	30	6	36
High (> 149.5)	6	6	12
Total	36	12	48

% Correct = 36/48 = 75.0%
Sensitivity = 6/12 = 50.0%

a 68.6 ng/m^3 = 50th percentile for the 48 asbestos-containing friable material sites.
b 149.5 ng/m^3 = 75th percentile for the 48 asbestos-containing friable material sites.

Table 39. Predicting Low/High Airborne Chrysotile Concentration with Three Regression-based Dichotomies

Distribution of the 48 Asbestos-containing Friable Material Sites: Observed Airborne Chrysotile Concentration Versus Predicted

Observed airborne chrysotile concentration (ng/m^3)	Predicted by seven algorithm factors[a] (Regression model I, Table 31)		Total
	Low (≤ 149.5)	High (> 149.5)	
Low (≤ 149.5[b])	36	0	36
High (> 149.5)	10	2	12
Total	46	2	48

% Correct = 38/48 = 79.2%
Sensitivity = 2/12 = 16.7%

Observed airborne chrysotile concentration (ng/m^3)	Predicted by six algorithm factors[c] and releasability[d] (Regression model II, Table 31)		Total
	Low (≤ 149.5)	High (> 149.5)	
Low (≤ 149.5)	35	1	36.
High (> 149.5)	9	3	12
Total	44	4	48

% Correct = 38/48 = 79.2%
Sensitivity = 3/12 = 25.0%

Observed airborne chrysotile concentration (ng/m^3)	Predicted by releasability[d], room volume, and water damage (Unweighted regression model, Table 34)		Total
	Low (≤ 149.5)	High (> 149.5)	
Low (≤ 149.5)	35	1	36
High (> 149.5)	9	3	12
Total	44	4	48

% Correct = 38/48 = 79.2%
Sensitivity = 3/12 = 25.0%

a Of the eight algorithm factors, exposure was not included because of zero variability. Bulk sample chrysotile content was included as the actual percentage instead of the original algorithm categorization.
b 149.5 ng/m^3 = 75th percentile for the 48 asbestos-containing friable material sites.
c Of the eight algorithm factors, exposure was not included because of zero variability, and friability was replaced by releasability category. Bulk sample chrysotile content was included as the actual percentage instead of the original algorithm categorization.
d Releasability category.

Table 40. Predicting Low/High Airborne Chrysotile Concentration with Other Regression-based Dichotomies

Percentage of the 48 Asbestos-containing Friable Material Sites Correctly Classified

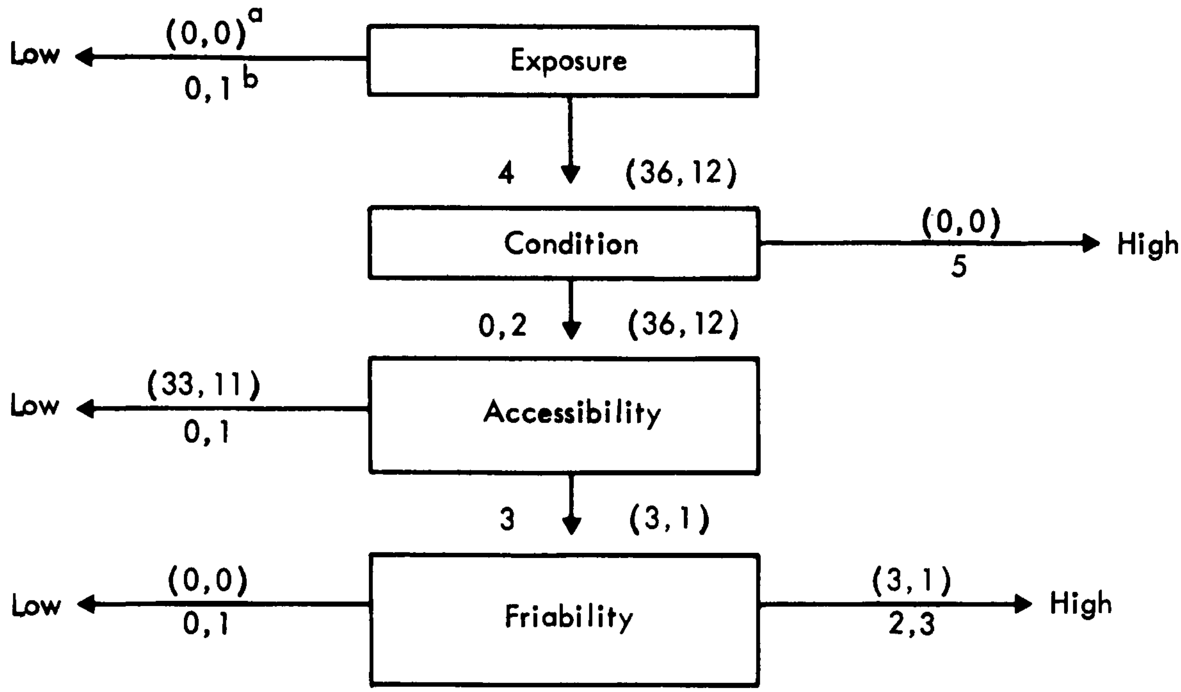
Independent variables in the regression model	Airborne chrysotile concentration cut point	
	68.6 ng/m^3 [a]	149.5 ng/m^3 [b]
Releasability (nine ranks) and six algorithm factors[c]	60.4%	77.1%
Releasability (nine ranks), room volume, and water damage	60.4%	77.1%

a 68.6 ng/m^3 = 50th percentile for the 48 asbestos-containing friable material sites.

b 149.5 ng/m^3 = 75th percentile for the 48 asbestos-containing friable material sites.

c Of the eight algorithm factors, exposure was not included because of zero variability, and friability was replaced by releasability rank.

Table 41. Predicting Low/High Airborne Chrysotile Concentration with the Original Decision Tree Based upon Proportion of Material Exposed, Material Condition, Accessibility, and Friability



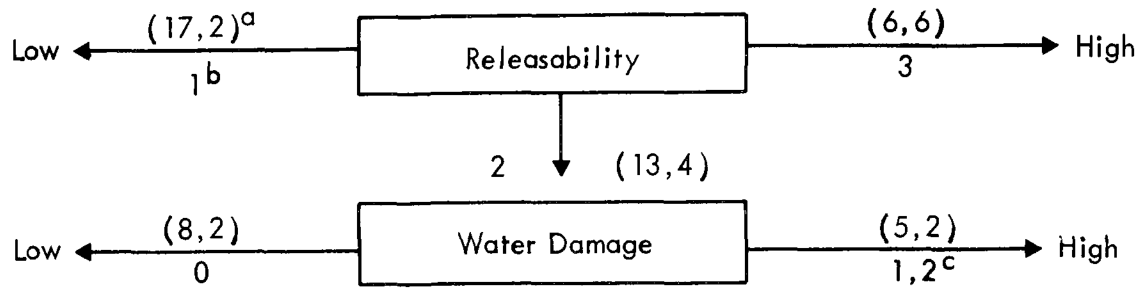
Distribution of the 48 Asbestos-containing Friable Material Sites: Low/High Airborne Chrysotile Concentration - Observed Versus Predicted by Decision Tree

Observed airborne chrysotile concentration (ng/m^3)	Predicted by tree: Low	Predicted by tree: High	Total
Low (≦ 149.5[c])	33	3	36
High (> 149.5)	11	1	12
Total	44	4	48

% Correct = 34/48 = 70.8%
Sensitivity = 1/12 = 8.3%

a Number of sites with low airborne chrysotile concentration (≦ 149.5 ng/m^3), number of sites with high airborne chrysotile concentration (> 149.5 ng/m^3).
b Algorithm factor codes.
c 149.5 ng/m^3 = 75th percentile for the 48 asbestos-containing friable material sites.

Table 42. Predicting Low/High Airborne Chrysotile Concentration with a Decision Tree Based upon Releasability and Water Damage



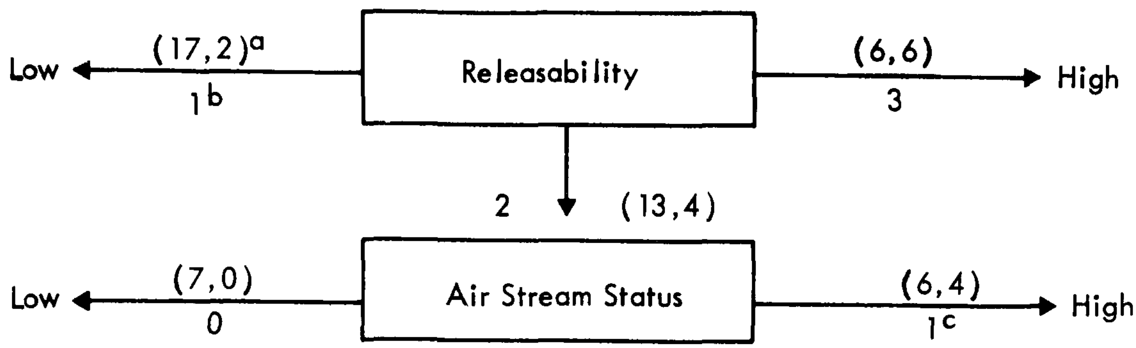
Distribution of the 48 Asbestos-containing Friable Material Sites: Low/High Airborne Chrysotile Concentration - Observed Versus Predicted by Decision Tree

Observed airborne chrysotile concentration (ng/m^3)	Predicted by tree: Low	Predicted by tree: High	Total
Low (≦ 149.5[d])	25	11	36
High (> 149.5)	4	8	12
Total	29	19	48

% Correct = 33/48 = 68.8%
Sensitivity = 8/12 = 66.7%

a Number of sites with low airborne chrysotile concentration (≦ 149.5 ng/m^3), number of sites with high airborne chrysotile concentration (> 149.5 ng/m^3).
b Releasability codes: 1 = ranks 1-4, 2 = ranks 5-6, 3 = ranks 7-9.
c Water damage codes.
d 149.5 ng/m^3 = 75th percentile for the 48 asbestos-containing friable material sites.

Table 43. Predicting Low/High Airborne Chrysotile Concentration with a Decision Tree Based upon Releasability and Air Stream Status



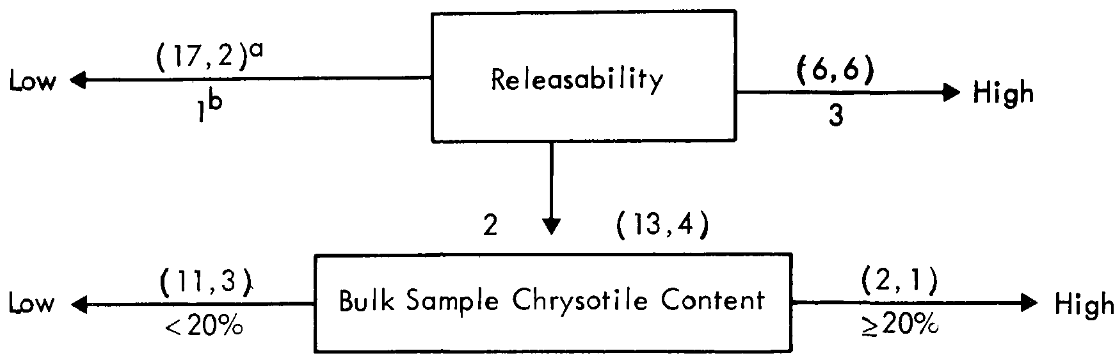
Distribution of the 48 Asbestos-containing Friable Material Sites: Low/High Airborne Chrysotile Concentration - Observed Versus Predicted by Decision Tree

Observed airborne chrysotile concentration (ng/m^3)	Predicted by tree		Total
	Low	High	
Low ($\leq$ 149.5[d])	24	12	36
High (> 149.5)	2	10	12
Total	26	22	48

% Correct = 34/48 = 70.8%
Sensitivity = 10/12 = 83.3%

a Number of sites with low airborne chrysotile concentration ($\leq$ 149.5 ng/m^3), number of sites with high airborne chrysotile concentration (> 149.5 ng/m^3).
b Releasability codes: 1 = ranks 1-4, 2 = ranks 5-6, 3 = ranks 7-9.
c Air stream status codes.
d 149.5 ng/m^3 = 75th percentile for the 48 asbestos-containing friable material sites.

Table 44. Predicting Low/High Airborne Chrysotile Concentration with a Decision Tree Based upon Releasability and Bulk Sample Chrysotile Content



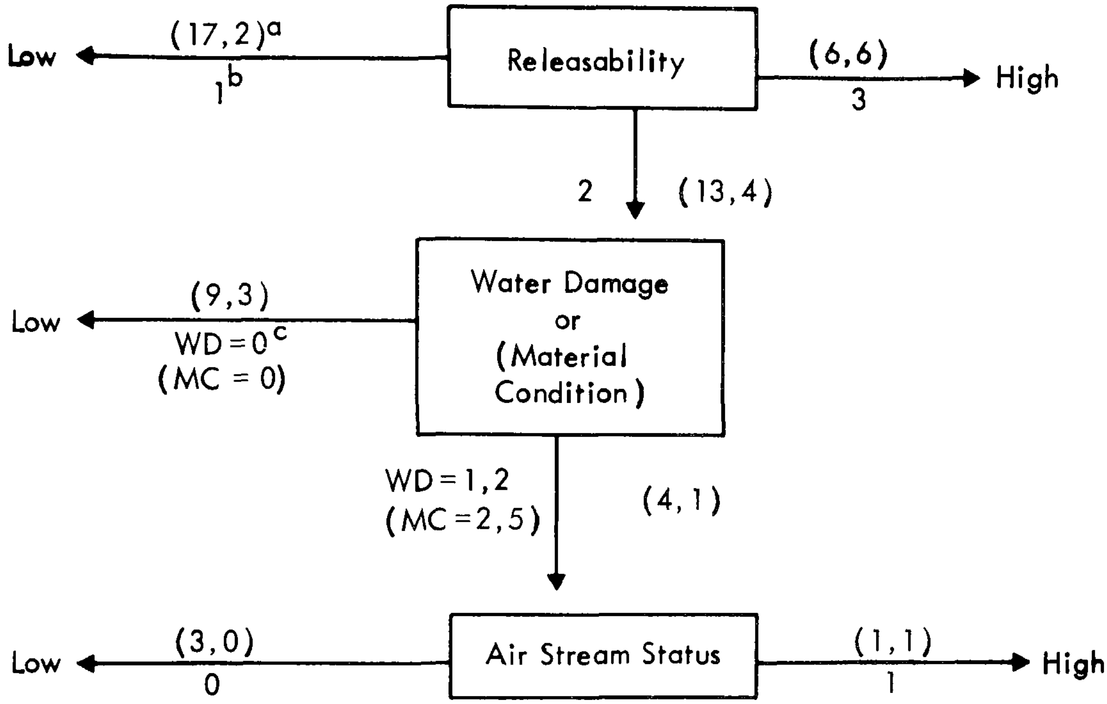
Distribution of the 48 Asbesots-containing Friable Material Sites: Low/High Airborne Chrysotile Concentration - Observed Versus Predicted by Decision Tree

Observed airborne chrysotile concentration (ng/m^3)	Predicted by tree		Total
	Low	High	
Low (≦ 149.5[c])	28	8	36
High (> 149.5)	5	7	12
Total	33	15	48

% Correct = 35/48 = 72.9%
Sensitivity = 7/12 = 58.3%

a Number of sites with low airborne chrysotile concentration (≦ 149.5 ng/m^3), number of sites with high airborne chrysotile concentration (> 149.5 ng/m^3).
b Releasability codes: 1 = ranks 1-4, 2 = ranks 5-6, 3 = ranks 7-9.
c 149.5 ng/m^3 = 75th percentile for the 48 asbestos-containing friable material sites.

Table 45. Predicting Low/High Airborne Chrysotile Concentration with a Decision Tree Based upon Releasability, Water Damage (or Material Condition), and Air Stream Status



Distribution of the 48 Asbestos-containing Friable Material Sites: Low/High Airborne Chrysotile Concentration - Observed Versus Predicted by Decision Tree

Observed airborne chrysotile concentration (ng/m^3)	Predicted by tree Low	Predicted by tree High	Total
Low (≦ 149.5[d])	29	7	36
High (> 149.5)	5	7	12
Total	34	14	48

% Correct = 36/48 = 75.0%
Sensitivity = 7/12 = 58.3%

a Number of sites with low airborne chrysotile concentration (≦ 149.5 ng/m^3), number of sites with high airborne chrysotile concentration (> 149.5 ng/m^3).
b Releasability codes: 1 = ranks 1-4, 2 = ranks 5-6, 3 = ranks 7-9.
c Water damage and (material condition) codes.
d 149.5 ng/m^3 = 75th percentile for the 48 asbestos-containing friable material sites.

Two points should be considered before the most "successful" classification analyses can be identified from the various discriminant, univariate, regression, and decision tree approaches presented in Tables 35 through 45 and in Appendix G. First, if sites with several hundred nanograms per cubic meter of airborne chrysotile are of primary concern, then attention could focus upon those analyses which used the 75th airborne chrysotile percentile to identify high/low airborne chrysotile sites because all of the observed "high" sites had airborne levels in excess of 149.5 ng/m^3. Second, when classification tables are inspected, equal attention could be paid to "the overall percentage of observations correctly classified" and to the "sensitivity" of the analysis. In the present context, sensitivity can be defined as the percentage of observed (true) high airborne chrysotile sites predicted by the variables in the model or the tree. More specifically, if most sites are observed low, then a classification procedure which predicts all sites to be low will have a high overall percentage of sites correctly classified. However, its sensitivity to detecting high level sites will be zero. Table 46 displays a summary of the classification analyses based upon the 75th airborne chrysotile percentile.

Inspection of Table 46 reveals that all of the analyses based upon the higher cutpoint (75th percentile) yielded a percentage of total observations correctly classified in excess of 68.0 except for the univariate score dichotomy which yielded a (low) percentage of 47.9. This relatively poor performance of the algorithm score is consistent with earlier findings. Table 46 also highlights the large range of sensitivity statistics yielded by the various analyses. The very lowest sensitivity (8.3%) is associated with the original version of the decision tree based upon exposed surfaces, material condition, accessibility, and friability. The highest sensitivity (83.3%) is associated with the decision tree based upon releasability and airstream status. In the light of the information summarized in Table 46, the optimal classification analysis appears to be a decision tree based upon releasability and airstream status. Yet more research needs to be done to reduce the number of false positives yielded by this tree (see Table 43). In addition, it should be noted that a discriminant model (based upon the 75th percentile cut point, releasability, and airstream status with equal prior probabilities) can be designed to yield the same classification results as the optimal tree. Moreover, the sensitivity of this discriminant model can be increased to 92% (if the prior probabilities of classification are .25 and .75, but the overall percentage correct drops to 48.0). The advantage of a decision tree versus a discriminant function is that the former is easily understood by nonstatisticians.

V. COMPARISON OF RATERS

Each of the 48 student areas selected for the study was rated by five researchers from the project team on each assessment factor--condition, accessibility, part of air moving system, exposure, water damage, activity, and friability (see Site-Specific Ratings in Section 5). The raters acted independently at each student area to provide data that reflect the measurement precision that is associated with the factors. In addition, after the rating was completed at each site, the five raters reached a consensus rating for each factor. The consensus ratings were reported and used in the statistical

Table 46. Classification Analysis Summary (Airborne Chrysotile Concentration 75th Percentile Dichotomy)

Analytical approach	Table	Independent variables	Results	
			Sensitivity[a] (%)	% Correctly classified[b]
Discriminant analysis	36	7 algorithm factors	25.0	79.2
	36	Releasability rank and 6 algorithm factors	41.7	81.2
Univariate dichotomy	37	Algorithm score (L/H dichotomy)	25.0	47.9
	38	Releasability (L/H dichotomy)	50.0	75.0
Regression analysis	39	7 algorithm factors	16.7	79.2
	39	6 algorithm factors and releasability category	25.0	79.2
	39	Releasability category, room volume, and water damage	25.0	79.2
	40	Releasability rank and 6 algorithm factors	25.0	77.1
	40	Releasability rank, room volume, and water damage	16.7	77.1
Decision tree	41	Proportion of material exposed, material condition, accessibility, and friability	8.3	70.8
	42	Releasability category and water damage	66.7	68.8
	43	Releasability category and air stream status	83.3	70.8
	44	Releasability category and bulk sample chrysotile content	58.3	72.9
	45	Releasibility category, water damage (or material condition), and air stream status	58.3	75.0

a Percentage of the 12 observed "high" sites correctly classified by the independent variables.

b Percentage of the 48 asbestos-containing friable material sites correctly classified by the independent variables.

analysis of the relationship between factors and measured airborne asbestos concentration levels.

Any application of the factors or combination of factors as a method of ordering the severity of asbestos exposure among schools or student areas within schools will probably involve only one rater. The use of a consensus in this study is an operational method to reduce the actions of five raters to that of one rater. The additional rating data give information on the internal consistency of the factors. Lack of variation among raters is an indication that the factors are measuring well-defined characteristics. Wide variation among raters suggests that the factors are measuring poorly defined characteristics. An assessment of consistency was performed by comparing individual ratings with the consensus rating.

There are a variety of methods to summarize the rater data to reflect the degree of consistency in the factors. For the purposes of this analysis, the number and proportion of disagreements between individual ratings and consensus ratings were used. Table 47 displays the basic data. The rows correspond to the 48 asbestos-containing friable material sites within schools. Column 1 is an identifying code. Columns 2 through 8 correspond to the exposure assessment algorithm factors. The values appearing in each column are counts of the number of rater disagreements with the consensus rating. For example, in row 1, column 4, the 1 indicates that one individual rating disagreed with the consensus on the factor air movement at student area 5-1. In row 22 (labeled 55-1), the 3 in column 6 indicates that three individual ratings disagreed with the consensus rating on water damage at student area 55-1.

The last two rows of the table are summaries. The row labeled "count" contains a row count of the number of student areas from among the 48 where there was <u>any</u> type of disagreement; the row labeled "total" contains the total number of disagreements tabulated over all student areas. Columns 9 and 10 are similar summaries taken across factors for each student area. For example, at student area 5-2 there was disagreement on two factors (activity and friability) with a total of three disagreements (two on activity and one on friability).

In total, there are 1,680 opportunities for disagreement (5 raters, 7 factors, 48 student areas). There were 166 disagreements observed. Assuming that the raters treated each factor at each student area as an independent rating, an estimate of the rate of disagreement is .099 (9.9%). Using a 95% confidence interval as an approximation to assess the variability in the estimate indicates that it is unlikely that the disagreement rate exceeds .113 (11.3%).

From the last row in Table 47 there is an indication that the factors activity and friability may be less reliable than the other five factors. The percentages of disagreement for these two factors are 17.5% and 14.2%, respectively. The maximum disagreement percentage taken over the remaining five factors is 10.4%. An analysis of variance computation to compare disagreement proportions among factors indicated significant differences (see Table 48). This result suggests that activity and friability are harder to measure than the other factors and merits further consideration. Indeed, this result highlights the relative subjectivity of the factor rating procedures used in the application of the algorithm.

Table 47. Rater Consistency:Disagreement with Consensus Frequencies

School site	Factor							Summary	
	Cond.	Access.	Air	Exp.	WDam.	Activ.	Fri.	Count	Total
1-1			1					1	1
1-2						2	1	2	3
1-3						2		1	2
2-1			2					1	2
2-2	1						1	2	2
2-3	2							1	2
2-4	1	1	1			1	1	5	5
3-1						2	1	2	3
3-2	1					1		2	2
3-3							1	1	1
3-4			1				1	2	2
4-1	1					1		2	2
5-1		2			1	1	1	4	5
6-1			1			2		2	3
6-2			1					1	1
6-3			1					1	1
7-1	1	1				2	2	4	6
7-2	1	1			2	1	1	5	6
7-3	1					2	2	3	5
8-1	1					1		2	2
9-1	2	1	2			1		4	6
10-1		1	1		3	2	1	5	8
11-1	2	2	2		2	2	1	6	11
12-1		2	1			1		3	4
12-2		2	1					2	3
13-1		1				1		2	2
13-2		1			1	1	2	4	5
13-3						3	2	2	5
14-1	2					1	1	3	4
14-2	2		1		2	2	1	5	8
14-3	2	1	1		1	2	1	6	8
15-1	1				1	1		3	3
16-1							2	1	2
17-1			1				3	2	4
18-1		1			2			2	3
19-1		1				2	1	3	4
20-1			1		1	1	1	4	4
20-2	1	1	1		1	1	1	4	4
21-1	1				1	1	1	4	4
21-2								0	0
22-1					1	1		2	2
22-2	1							1	1
23-1			3		1		3	3	7
24-1	1				3		1	3	5
24-2						1		1	1
25-1								0	0
25-2			1				1	2	2
25-3								0	0
COUNT	19	15	19	0	14	29	25	121	
TOTAL	25	19	24	0	22	42	34		166

Table 48. Analysis of Variance for Disagreement Proportions[a]

Source	Sum of squares	df	Mean square	F Ratio
Asbestos-containing material sites	1.813	47	0.039	1.95
Factors	0.310	5	0.062	3.10[b]
Error	4.753	235	0.020	
TOTAL	6.876	287		

a The calculations were performed on ratios obtained as the number of disagreements divided by the number of raters (five in each case). The factor "exposure" was excluded since all student areas were rated as being exposed.

b $p = .05$.

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APPENDIX A

DESIGN CONSIDERATIONS AND SAMPLING SCHEME

SAMPLE DESIGN AND SELECTION

After consideration and development of the informational requirements needed to satisfy the objectives of the study, the first step in designing a survey is to determine the population and subpopulations of interest, the parameters to be estimated, and constraints with respect to estimation precision, cost, and time. Given the statement of the informational requirements, operational study population definitions can be developed and appropriate sampling frames constructed. The sample design and survey operating procedures can then be developed to meet the estimation precision and cost requirements. Given the probability structure specified by the sample design, the appropriate statistical analyses can be prescribed.

The design of the survey for this study of airborne asbestos levels in schools involved many operationally complex issues, e.g., air sampling instrumentation and methodology, logistics regarding both equipment and field staff, and laboratory analysis methodology. This appendix gives the considerations in development of the survey design (USEPA 1981). This appendix also describes the sample design and the results of sample selection.

I. DESIGN CONSIDERATIONS

A. Objective One

The first objective of the study was to collect air sampling data in order to document potential exposure to airborne asbestos from asbestos-containing materials in schools. A number of air sampling studies have been conducted to establish the level of airborne asbestos in public buildings and in specific areas of buildings where asbestos-containing materials are present and to compare these levels to ambient concentrations. Nicholson (1978) reported on ambient asbestos samples collected in 48 U.S. cities in 1969 and 1970. The majority of ambient samples contained less than 20 ng/m^3 of asbestos. Other studies reported by Nicholson that measured airborne asbestos both inside and outside buildings showed indoor averages ranging from 2.5 to 200 ng/m^3 and outdoor averages from 0 to 48 ng/m^3. In Paris airborne asbestos concentrations inside public buildings and outdoors were studied from 1974 through 1976 (USEPA 1980f). The results showed ambient concentrations of chrysotile asbestos, with maximum concentration observed to be 10 ng/m^3. The distribution of airborne asbestos concentrations inside buildings where asbestos-containing materials were identified ranged from below 10 ng/m^3 to approximately 800 ng/m^3.

The results of these studies provide evidence that airborne asbestos levels are elevated when asbestos-containing materials are present. None of these previous studies, however, had a probability sample design to estimate airborne levels in a defined study population.

Plans for the current study specified that airborne asbestos concentration levels were to be determined by air sampling to collect fibers on a filter followed by transmission electron microscopy analysis to estimate concentrations in nanograms per cubic meter (ng/m^3). The indoor concentrations at sites where asbestos-containing materials were present were to be compared with those at indoor sites where no asbestos was present and with ambient levels. At each school where air sampling was conducted, an indoor control sample and an ambient sample were also to be collected.

From a statistical perspective the ideal way to accomplish the first objective is to do a national study of schools, and sites within schools selected according to a probability sample design. The study results would provide unbiased national estimates along with stated precision of the airborne asbestos concentration levels and the concentration differential between suspect sites and controls. However, it was determined that a national study was neither feasible nor necessary at this time. Difficulties associated with soliciting cooperation of school systems, establishing background information to support the implementation of the sampling design, and transporting equipment and staff throughout the nation would delay the results beyond the point in time when they could be useful to U.S. EPA for rulemaking. In addition, if airborne asbestos concentrations were found to be elevated in one school system where asbestos-containing materials were present, that evidence would be sufficient to alert other school systems of the potential problem.

One large urban school district had begun its own program to assess asbestos exposure. It had identified many schools that had asbestos present by collecting and analyzing bulk samples. Also, it had scored areas within these schools on algorithm factors. These data served as a base for constructing stratification variables. A probability sample design was developed for this school district.

B. Objective Two

The second objective of the study was to determine the best combination of factors for predicting airborne asbestos levels in schools. The exposure assessment tools to be considered in this study were based on the factors of the algorithm (Table A-1) and a measurement of the percentage of asbestos present in the site material by analyzing bulk samples taken from the site. The primary goal in assessing exposure to asbestos in schools is to be able to initiate corrective action in those situations that present an unreasonable risk to the health of persons who use school buildings.

Of concern is the validity of exposure assessment (decision) rules related to taking a corrective action or deferring action to a later time. Two general types of assessment rules are considered. The first is characterized by an approximately continuous measurement scale that allows for differentiation among air levels at all points on the scale. The second is characterized by a discrete measurement scale that differentiates only between high and low levels of airborne asbestos concentrations. To highlight the design requirements for the second objective, the framework underlying each type of rule is described by specific examples of the two types of rules.

For the first case, the algorithm is used. A score is produced by summing factors 1 through 6 and multiplying the sum by factors 7 and 8. (Refer to Table A-1 for a description of the factors.) When considering this algorithm, the decision rule is derived from the relationship between air levels

Table A-1. Algorithm Factors and Their Weighted Scores

Factor	Weighted score
1. Condition	
No damage	0
Moderate damage	2
Severe damage	5
2. Accessibility	
Not accessible	0
Rarely accessible	1
Accessible	3
3. Part of air moving system	
No	0
Yes	1
4. Exposure	
Material not exposed	0
10% or less of the material exposed	1
Greater than 10% of the material exposed	4
5. Water damage	
No water damage	0
Minor water damage	1
Moderate or major water damage	2
6. Activity or movement	
None or low activity level	0
Moderate activity level	1
High activity level	2
7. Friability	
Not friable	0
Low friability	1
Moderate friability	2
High friability	3
8. Percentage asbestos	
Less than or equal to 1%	0
Greater than 1% and less than or equal to 50%	2
Greater than 50%	3

of asbestos and algorithm scores. Conceptually, the relationship takes the form shown in Figure A-1. As the score increases, airborne asbestos concentration increases. In the figure, A_o represents the airborne asbestos level that defines the cutoff point between safe and unsafe levels. A_o in turn determines S_o on the algorithm scale that represents the cutoff point defining corrective action versus the deferral of corrective action. It is desirable to be able to specify a value of A_o as a cutoff point. Therefore, validation of the algorithm as an exposure assessment tool is based on demonstrating that there is a high level of precision associated with the establishment of the curve in Figure A-1.

For the second case, the decision tree algorithm (DTA) is considered as an example. Each factor outcome is reduced to a dichotomy. The decision rule for action or deferred action arises from the classification of sites into one of two groups. For convenience, the groups are named Action (Group A) and Deferred Action (Group DA). The site is classified into A or DA according to the tree shown in Figure A-2. Using four factors to define the decision tree, there are 16 types of sites shown in Table A-2. Five sites belong to Group A; 11 sites belong to Group DA. From a conceptual perspective, there is a distribution of airborne asbestos concentrations corresponding to each group (see Figure A-3). Validation of DTA involves the comparison of the characteristics of these distributions.

When confronted with both a validation and a development objective, as is the case here, it can be difficult to specify a sample design that is simultaneously satisfactory for each. Since the assessment tools to be evaluated will all be derived from the eight factors in Table A-1, it is intuitively appealing to suggest that air sampling data should be collected under all combinations of the factors. Then the relationship between airborne asbestos concentrations and factors can be thoroughly investigated in search of a "best" assessment tool. Unfortunately, this approach is unrealistic because (1) the total number of combinations determined by these factors is 944,784, which is unmanageable, and (2) it is not possible to know which combinations actually exist in any specified study area until the sites are visited and scored. Additionally, the distribution of the sample sites among the existing factor combinations that is optimal (in terms of estimation precision) for this second objective is not the same as the distribution that is optimal for the first objective. This is because the algorithm factor combinations are not present in equal proportions in the study population, and oversampling certain subgroups (here, factor level combinations) to facilitate subgroup estimation tends to reduce the overall estimation precision. Thus, the two objectives have mutually conficting implications for the sample design. The sample design employed for this survey involved a "compromise approach," imposing constraints towards satisfying both objectives. Of course, the estimation precision associated with each objective is somewhat less than it would be under a design developed to satisfy just the one objective.

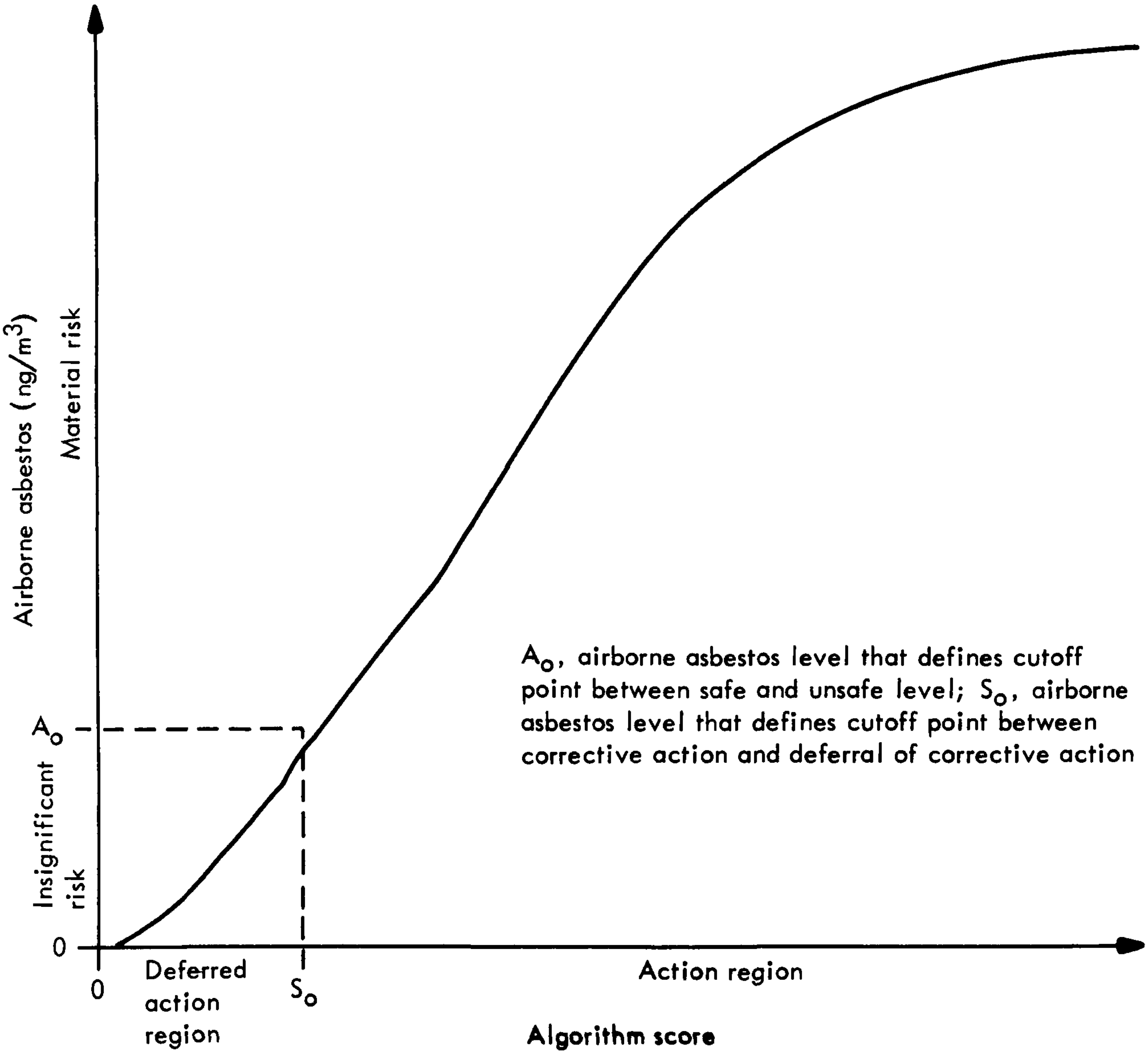

Figure A-1. Hypothesized relationship between air level and algorithm score.

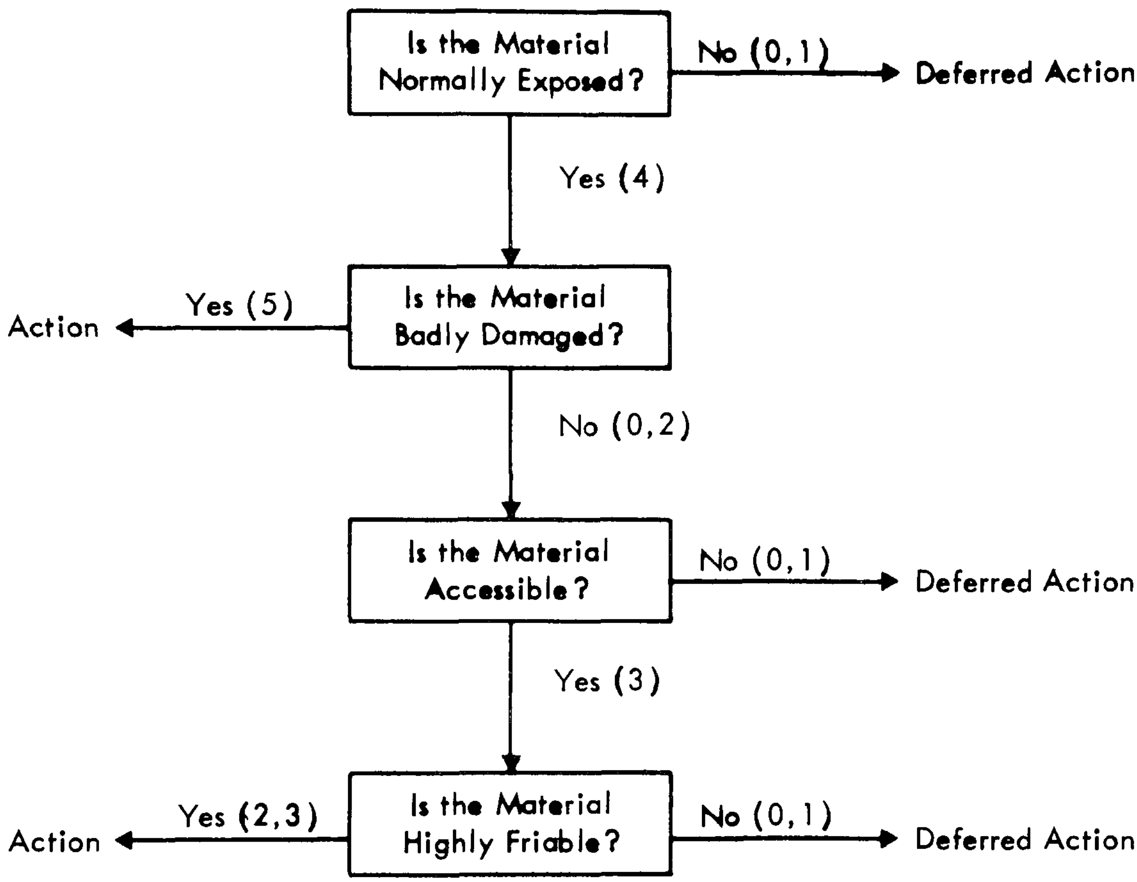

Figure A-2. Original asbestos exposure assessment decision tree. Applied to sites with > 1% asbestos in bulk sample. Numbers in parentheses are weighted algorithm scores. (Source: decision tree formulated in 1980 by Battelle researchers and U.S. EPA task leader.)

Table A-2. Site Description for Decision Tree Algorithm[a]

Site no.	Factor				Group[b]
	Friability	Condition	Exposure	Accessibility	
2	Low	Good	Low	High	DA
3	Low	Good	High	Low	DA
5	Low	Bad	Low	Low	DA
8	Low	Bad	High	High	A
9	High	Good	Low	Low	DA
12	High	Good	High	High	A
14	High	Bad	Low	High	DA
15	High	Bad	High	Low	A
17	Low	Good	Low	Low	DA
20	Low	Good	High	High	DA
22	Low	Bad	Low	High	DA
23	Low	Bad	High	Low	A
26	High	Good	Low	Low	DA
27	High	Good	High	Low	DA
29	High	Bad	Low	Low	DA
32	High	Bad	High	High	A

a Applied to sites with > 1% asbestos in bulk sample.
b DA - deferred action; A - action.

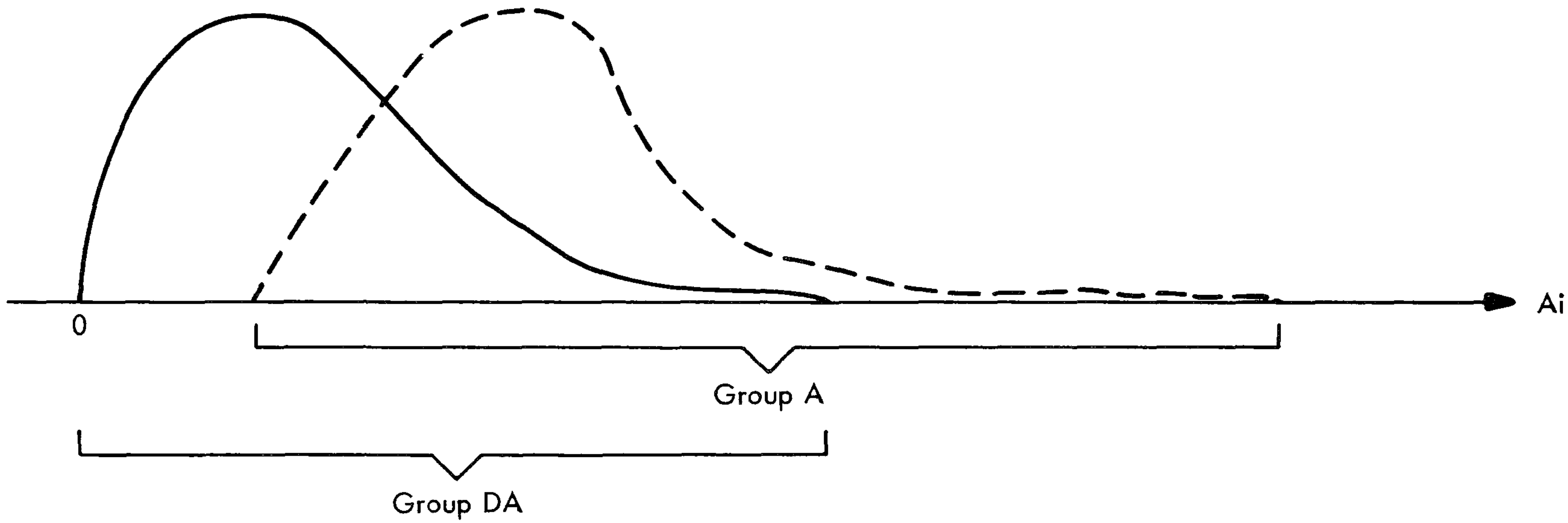

Figure A-3. Hypothetical distribution of airborne asbestos concentration levels. Group A, action; Group DA, deferred action.

II. SAMPLE DESIGN

A. First-Stage Sample

1. Construction and Stratification of the First-Stage Frame

The first-stage frame consisted of all schools having student areas in which material suspected of containing asbestos was present. This list of schools was compiled on April 28, 1981, from the school district's asbestos program information.

The first-stage frame was stratified into nine classes formed by considering three categories of asbestos content--low, high, and unknown--with three categories of friability--low, moderate, and high. These nine classes, or strata, are listed in Table A-3. Schools were classified according to the asbestos content and friability of the sampling area. If a school contained more than one sampling area and if those sampling areas differed as to asbestos content and friability, the school was placed into the stratum (among those strata corresponding to sampling areas in the school) that had substantially fewer schools. If no stratum corresponding to a sampling area in the school contained substantially fewer schools than the others, then the school was stratified according to the sampling area of largest area.

Table A-3. First-Stage Strata, Constructed from Asbestos Content and Friability Categories

Stratum	Asbestos content[a]	Friability[b]
1	Low	Low
2	Low	Moderate
3	Low	High
4	High	Low
5	High	Moderate
6	High	High
7	Unknown	Low
8	Unknown	Moderate
9	Unknown	High

a Asbestos content taken from school district's asbestos program laboratory results known as of April 28, 1981.
Low: $>$ 1% and $<$ 20% asbestos
High: $\geq$ 20% asbestos
Unknown: Laboratory results not known as of April 28, 1981.

b Friability ratings taken from worksheets prepared by school district personnel during inspection of schools for its asbestos program.
Low: Rated 1
Moderate: Rated 2
High: Rated 3

For stratification of the first-stage frame, asbestos content was taken from the district's asbestos program laboratory results that were known as of April 28, 1981. Low asbestos content was defined as asbestos present at a concentration less than 20%. (Asbestos was said to be present if the average asbestos concentration for the sampling area exceeded 1%.) High asbestos content was defined as asbestos concentration equal to or greater than 20%. Friability ratings used in stratification were taken from worksheets prepared by district personnel during their inspection of schools for their asbestos program.

2. Allocation and Selection of the First-Stage Sample

The allocation of the 25 sample schools among the nine first-stage strata is shown in Table A-4. Of the 25 sample schools, 14 were selected from strata 1 through 6 (asbestos content known), and 11 were selected from strata 7 through 9 (asbestos content unknown). This allocation between the two groups is not in proportion to size or enrollment; an allocation proportional to enrollment would result in selecting 8 schools from strata 1 through 6 and 17 schools from strata 7 through 9. More schools were selected from strata 1 through 6, asbestos content known, to ensure the desired distribution of sample schools with respect to level of asbestos content in combination with level of friability. Among strata 7 through 9, the 11 sample schools were allocated in proportion to enrollment, subject to the restriction that at least one school be selected from each first-stage stratum. Among strata 1 through 6, the 14 sample schools were allocated approximately in proportion to enrollment but with slightly greater emphasis on high asbestos content as opposed to low asbestos content.

Table A-4. Allocation of Sample Schools Among First-Stage Strata

Stratum	Asbestos content	Friability	Number of sample schools
1	Low	Low	1
2	Low	Moderate	3
3	Low	High	3
4	High	Low	1
5	High	Moderate	4
6	High	High	2
Total for strata 1 to 6			14
7	Unknown	Low	1
8	Unknown	Moderate	9
9	Unknown	High	1
Total for strata 7 to 9			11
TOTAL			25

The required number of schools (Table A-4) was selected from each stratum with probability proportional to size and without replacement. School enrollment was used as a size measure. The preferred size measure would have been the number of eligible sites suspected of containing asbestos per school. However, this information was not readily available, and it was thought that school enrollment would have a fairly strong positive relationship with this number. A reason for selection with probability proportional to size is to have selection probabilities at the first stage such that a self-weighting (to the extent possible given the design constraints) sample can be obtained at the final stage. For a discussion of selection with probability proportional to size, see Kish (1965). Note that the design constraints cause this sample not to be self-weighting. Hence, to obtain parameter estimates for the school district, weighted statistical analysis is required. To obtain valid estimates in a superpopulation setting requires that cell means be based on weighted estimates.

3. First-Stage Selection Probabilities

The selection probability for a school is equal to the ratio of the school's enrollment to the total enrollment for its stratum multiplied by the number of schools selected from that stratum. Table A-5 gives selection probabilities for the 25 sample schools. These selection probabilities were used in calculating sampling weights for statistical analysis of the data, as described in Section 7 of this report.

B. Second-Stage Sample

1. Construction and Stratification of the Second-Stage Frame

The second-stage frame consisted of all eligible sites suspected of having asbestos-containing material in the first-stage sample of 25 schools. These sites were counted and listed using the marked floor plans that were prepared by school district personnel for the school district's asbestos program. (Because of time constraints, no school visits for the purpose of counting and listing eligible sites were possible.) The second-stage frame was stratified according to the presence or absence of asbestos-containing material.

Table A-6 gives the number of asbestos-containing material sites on the second-stage frame by school and friability/condition/exposure/accessibility category. These categories are described in Table A-7. A site was placed in a category according to the rating its entire sampling area received from school district personnel. Ratings for individual sites were not readily available. With the exception of three sample schools, all eligible sites from the same sample school fell into the same friability/condition/exposure/accessibility category. This was, in part, because schools often had only one or two eligible sampling areas, and because sites were classified by sampling area ratings.

Table A-5. Probabilities of Selection for Sample Schools

School code	First-stage stratum	Probability of selection
22	1	.3202
20	2	.2147
13	2	.5228
21	2	.2147
25	3	.2953
6	3	.9130
23	3	.1830
24	4	1.0000
9	5	.7364
3	5	1.0000
8	5	.5186
16	5	.1815
4	6	.5726
15	6	.1554
11	7	.2464
14	8	.1982
5	8	.2028
17	8	.0785
18	8	.2660
2	8	.2265
7	8	.3005
1	8	.3915
12	8	.3968
19	8	.0536
10	9	.2855

Table A-6. Number of Eligible Asbestos-Containing Material Sites on Second-Stage Frame

School code	Friability/condition/exposure/accessibility/category[a] 3	11	12	15	16	19	20	23	24	Total number of sites
22	39	0	0	0	0	0	0	0	0	39
20	0	32	0	0	0	0	0	0	0	32
13	0	0	56	0	0	0	0	0	0	56
21	0	30	0	0	0	0	0	0	0	30
25	0	0	0	0	0	11	13	0	0	24
6	0	0	0	0	0	60	0	0	0	60
23	0	0	0	0	0	0	0	0	37	37
24	38	0	0	0	0	0	0	0	0	38
9	0	0	51	0	0	0	0	0	3	54
3	0	0	111	0	0	0	0	0	0	111
8	0	2	0	0	0	0	0	0	0	2
16	0	16	0	0	0	0	0	0	0	16
4	0	0	0	0	0	1	0	1	0	2
15	0	0	0	0	0	1	0	0	0	1
11	17	0	0	0	0	0	0	0	0	17
14	0	40	0	0	0	0	0	0	0	40
5	0	7	0	0	0	0	0	0	0	7
17	0	11	0	0	0	0	0	0	0	11
18	0	1	0	0	0	0	0	0	0	1
2	0	0	0	0	0	76	0	0	0	76
7	0	0	0	0	96	0	0	0	0	96
1	0	0	0	83	0	0	0	0	0	83
12	0	40	0	0	0	0	0	0	0	40
19	0	9	0	0	0	0	0	0	0	9
10	0	0	0	0	0	0	0	4	0	4
Total number of sites	94	188	218	83	96	149	13	5	40	886

a Sites placed in categories according to sampling area ratings provided by school district. Categories not included on this table contained no sites from 25 sample schools, according to sampling area ratings. A description of the categories is provided in Table A-7.

Table A-7. Description of Friability/Condition/Exposure/Accessibility Categories

Category	Friability[a]	Condition[b]	Exposure[c]	Accessibility[d]
1	Low	Good	Low	Low
2	Low	Good	Low	High
3	Low	Good	High	Low
4	Low	Good	High	High
5	Low	Bad	Low	Low
6	Low	Bad	Low	High
7	Low	Bad	High	Low
8	Low	Bad	High	High
9	Moderate	Good	Low	Low
10	Moderate	Good	Low	High
11	Moderate	Good	High	Low
12	Moderate	Good	High	High
13	Moderate	Bad	Low	Low
14	Moderate	Bad	Low	High
15	Moderate	Bad	High	Low
16	Moderate	Bad	High	High
17	High	Good	Low	Low
18	High	Good	Low	High
19	High	Good	High	Low
20	High	Good	High	High
21	High	Bad	Low	Low
22	High	Bad	Low	High
23	High	Bad	High	Low
24	High	Bad	High	High

a Friability: Low = 1, Moderate = 2, High = 3
b Condition: Good = 0,2, Bad = 5
c Exposure: Low = 1, High = 4
d Accessibility: Low = 0,1, High = 4

2. Allocation and Selection of the Second-Stage Sample of Asbestos-Containing Material Sites

The second-stage sample of 48 asbestos-containing material sites was allocated among the 25 sample schools subject to the following restrictions: (1) at least one site must be selected from each of the 25 schools in the first-stage sample, and (2) at least one site must be selected from each nonempty friability/condition/exposure/accessibility category. To the extent possible, the second-stage sample was allocated among schools and friability/condition/exposure/accessibility categories proportional to the number of sites. Table A-8 displays this allocation.

As mentioned, eligible sites were listed using floor plans provided by the school district. For each school (or school and each category given in Table A-8), a starting point was selected on the school floor plan. From this starting point (a site), eligible asbestos-containing material sites were listed in order according to location. A random systematic sample of the required number of sites was then selected from this listing. This method was used because of the suspected tendency of nearby sites to resemble each other with respect to airborne asbestos levels. Systematic sampling assured a certain degree of spread in location among the selected sites within a school; i.e., it provided the benefits of a location stratification. (As can be noted from Table A-8, in 13 of the 25 sample schools, more than one site was selected.)

For each of the selected sites, alternate sites were also selected. Field personnel were to substitute an alternate site for a selected site whenever a selected site was found to be not eligible or whenever there was nonresponse (failure to obtain the required observation) at a selected site. A selected asbestos-containing material site was to be classified as not eligible if, contrary to floor plan information, the site was not being used as a student activity area or the site did not actually contain asbestos material. Nonresponse could occur, for example, if a teacher or school official would not permit air sampling at the selected site or if air sampling was not possible at the site because of lack of an electrical outlet, repeated vandalism, etc. An alternate site could not be substituted for a selected site simply because it might be more convenient for air sampling. These procedures for substitution were carefully followed by field personnel.

A summary of site selections, including alternate sites, is given in Table A-9. Of the 48 selected sites, nonresponse occurred at 6 sites, a nonresponse rate of 12%.

Table A-8. Allocation of Second-Stage Sample of Asbestos-Containing Material Sites Among Schools and Friability/Condition/Exposure/Accessibility Categories[a]

School code	Friability/condition/exposure/accessibility/category[a] 3	11	12	15	16	19	20	23	24	Number of sample sites
22	2	0	0	0	0	0	0	0	0	2
20	0	2	0	0	0	0	0	0	0	2
13	0	0	3	0	0	0	0	0	0	3
21	0	2	0	0	0	0	0	0	0	2
25	0	0	0	0	0	2	1	0	0	3
6	0	0	0	0	0	3	0	0	0	3
23	0	0	0	0	0	0	0	0	1	1
24	2	0	0	0	0	0	0	0	0	2
9	0	0	0	0	0	0	0	0	1	1
3	0	0	4	0	0	0	0	0	0	4
8	0	1	0	0	0	0	0	0	0	1
16	0	1	0	0	0	0	0	0	0	1
4	0	0	0	0	0	1	0	0	0	1
15	0	0	0	0	0	1	0	0	0	1
11	1	0	0	0	0	0	0	0	0	1
14	0	3	0	0	0	0	0	0	0	3
5	0	1	0	0	0	0	0	0	0	1
17	0	1	0	0	0	0	0	0	0	1
18	0	1	0	0	0	0	0	0	0	1
2	0	0	0	0	0	4	0	0	0	4
7	0	0	0	0	3	0	0	0	0	3
1	0	0	0	3	0	0	0	0	0	3
12	0	2	0	0	0	0	0	0	0	2
9	0	1	0	0	0	0	0	0	0	1
10	0	0	0	0	0	0	0	1	0	1
Number of sample sites	5	15	7	3	3	11	1	1	2	48

a Categories not included on this table contained no sites from 25 sample schools, according to sampling area ratings. A description of the categories is provided in Table A-7.

Table A-9. Asbestos-Containing Material Sites and Selection Probabilities in Second Stage of Selection

School code	Number of eligible sites with asbestos-containing material[a]	Site code	Probability of selection[b]
22	39	1	.0513
		2[c]	.0513
20	32	1	.0625
		2	.0625
13	56	1	.0536
		2	.0536
		3d	.0536
21	30	1	.0667
		2	.0667
25	11	1	.1818
		2	.1818
	13	3	.0769
6	60	1[c]	.0500
		2	.0500
		3[c]	.0500
23	37	1	.0270
24	38	1	.0526
		2[e]	.1579[e]
9	3	1	.0185[f]
3	111	1[g]	.0720[g]
		2	.0360
		3	.0360
		4	.0360
8	2	1	.5000
16	16	1	.0625
4	1	1	.5000[f]
15	1	1	1.0000
11	17	1	.0588
14	40	1	.0750
		2	.0750
		3	.0750
5	7	1	.1428
17	11	1	.0909

(continued)

Table A-9 (continued)

School code	Number of eligible sites with asbestos-containing material[a]	Site code	Probability of selection[b]
18	1	1	1.0000
2	76	1	.0526
		2[h]	.1053[h]
		3	.0526
		4[d]	.0526
7	96	1	.0312
		2	.0312
		3	.0312
1	83	1	.0361
		2	.0361
		3	.0361
12	40	1	.0500
		2[i]	.2000[i]
19	9	1	.1111
10	4	1[h]	.5000[h]

a According to school district floor plan information.
b Probability is conditional on first-stage sample of schools.
c Second alternate site was used. Nonresponse occurred at selected and first alternate sites.
d First alternate site was used. Nonresponse occurred at the selected site.
e Selected and first alternate sites were not eligible. Second alternate site was used, and selection probability was adjusted accordingly.
f Selection probability was adjusted to account for the nonrepresented category (see Tables A-6 and A-8) at this school.
g Nonresponse occurred at selected site. First and second alternates were not eligible. A third alternate site was used, and selection probability was adjusted accordingly.
h Selected site was not eligible. First alternate site was used, and selection probability was adjusted accordingly.
i Selected, first alternate, and second alternate sites were not eligible. A third alternate was used, and selection probability was adjusted accordingly.

3. Second-Stage Selection Probabilities for the Asbestos-Containing Material Sites

Conditional on the first-stage sample of schools, the selection probability of an asbestos-containing material site is calculated as the number of asbestos-containing material sites selected from the school (or school and each category given in Table A-8) divided by the number of eligible asbestos-containing material sites in the school (or school and each category given in Table A-8). The number of eligible asbestos-containing material sites counted using the marked school floor plan might not be the actual number of such sites. Some selected sites were in fact found to be not eligible, and alternate sites were substituted (Table A-9). In such a case, the number of sites selected divided by the number of sites listed is multiplied by the number of sites (selected and alternate sites) inspected to locate an eligible site suspected of containing asbestos. This value estimates the probability of site selection, conditional on the first-stage sample of schools. For example, consider school 10. Four sites were listed, and a site was randomly selected. Upon inspection, it was found that the selected site did not have asbestos-containing material. The first alternate was used for data collection. The site selection probability was then estimated using the following equation: (1 site selected/4 sites listed) x 2 sites inspected = (1/4) x 2 = .5000. This method arose from estimating the number of sites on the list that were eligible and suspected of containing asbestos by dividing the number of sites on the list by the number of chosen sites inspected to locate an eligible site suspected of containing asbestos.

The selection probabilities calculated here are conditional on the first-stage sample of schools. Thus a site's selection probability (conditional on the first-stage sample of schools) cannot be multiplied by the selection probability of its school to yield the overall selection probability of the site.

4. Selection of the Second-Stage Sample of Control Sites

At each of the 25 schools in the first-stage sample, a control site was selected. For a sample school, all student activity areas without asbestos-containing material were listed using the marked floor plan provided by the school district. A control site was randomly selected from this list. All sites on the list had equal probabilities of being selected. Alternate control sites were also selected. An alternate was used to replace a selected control site if, upon inspection by field personnel, it was found that the selected site was actually not eligible or if there was nonresponse. A selected site was ineligible if, contrary to floor plan information, the site was no longer being used as a student activity area or if the site did have material suggested of containing asbestos. (This process facilitates the estimation of list incompleteness for eligible sites suspected of containing asbestos.) Nonresponse refers to situations such as teacher or administrator refusal to allow air sampling at the selected site, lack of an electrical outlet needed to conduct air sampling, etc.

In one sample school, the marked floor plans indicated that there were no student activity areas without asbestos-containing material. In this case, all areas without asbestos-containing material were listed, though these areas were not student activity areas. A control site was randomly selected from this list. In a few other sample schools, the marked floor plans indicated that the schools contained no areas, student activity or not, without asbestos-containing material. In this situation, field personnel inspected the school to find an area without asbestos-containing material for conducting air sampling.

Table A-10 is a summary of control site selection. The probabilities of selection were calculated in the same way that the second-stage selection probabilities (see Table A-9) were calculated. There was no requirement that control sites be a specified distance from material suspected of containing asbestos. In other words, a control site could be immediately next door to a room with asbestos-containing material, or it could be on a floor entirely free of asbestos-containing material.

5. Selection of Outdoor Ambient Sites

At each school an outdoor site was selected to sample ambient air. This site was on the roof of the school building at a location remote from any school airflow ventilation exhaust point. No randomization process was involved in selecting a site's location outside the school building.

6. Selection of Bulk Sampling Locations

Three bulk samples of asbestos-containing material were collected at each of the 48 study sites. Bulk sampling locations were selected from each site according to the USEPA method (1980a, 1980b). This method involves use of a random number pair procedure to select a simple random sample of bulk sampling locations; all locations in the area of interest have equal probabilities of selection. Additionally, one of the three bulk sampling locations at each site was randomly selected for collection of duplicate (side-by-side) bulk samples.

C. Long-Term Sampling

At three sites randomly selected from the 48 sample sites, air sampling was conducted for three consecutive periods of 5 school days. The purpose of this sampling was to investigate the variability of airborne asbestos levels over time.

To select the three sites, the list of 48 sample sites was partitioned into three strata. Sites were first classified as to type of room. Auditoriums, libraries, cafeterias, and gymnasiums formed the first stratum. These types of rooms were selected from the standpoints of size and activity level. The remaining sites were classified according to asbestos content and friability, based on the school district's information at the sampling area level. The second stratum contained sites with high friability or a combination of high asbestos content and moderate friability. The third stratum contained the remaining sites. Tables A-11 through A-13 display the three strata.

One site was selected from each of the three strata, and within a stratum all sites had an equal probability of selection. The sites selected for long-term sampling are indicated in Tables A-11 through A-13.

Table A-10. Summary of Control Site Selection

School code	Number of eligible sites without asbestos-containing material	Probability of selection from its school
22	a	a
20	22	.0454
13	32	.0312[b]
21	2	.5000
25	10	.1000
6	69	.0290[c]
23	2	.5000
24	1	1.0000
9	5	.2000
3	a	a
8	d	d
16	5	.2000
4	80	.0125
15	20	.0500
11	73	.0274[c]
14	a	a
5	e	e
17	f	f
18	18	.0555
2	22	.0909[c]
7	14	.0714
1	51	.0196
12	16	.0625
19	9	.1111
10	82	.0122

a According to school district's floor plan information, school contained no areas without asbestos-containing material. Field personnel inspected school and found a non-student area without asbestos-containing material for control air sampling.

b First alternate was used as substitute for selected control site, due to a nonresponse situation.

c First alternate was used as substitute for selected control site because selected site was no longer being used as student area. Selection probability was adjusted accordingly.

d No school floor plan was available. Field personnel inspected school and located control site in a student area.

e No school floor plan was available. Field personnel inspected school and located control site in a non-student area.

f According to school district's floor plan information, school contained no student areas without asbestos-containing material. A non-student area was randomly selected to be used as a control site.

Table A-11. Selection of Long-Term Sampling Sites: Stratum 1[a]

School code	Site code
25	1
9	1
3	2
8	1
4	1
15	1
5	1
18	1
10	1[b]

a Large student activity areas (auditoriums, libraries, cafeterias, and gymnasiums).
b Site selected for long-term sampling.

Table A-12. Selection of Long-Term Sampling Sites: Stratum 2[a]

School code	Site code
25	2
	3
6	1
	2
	3
23	1
3	1
	3[b]
	4
16	1

a Classrooms and corridors with high friability or a combination of high asbestos content and moderate friability.
b Site was selected for long-term sampling.

Table A-13. Selection of Long-Term Sampling Sites: Stratum 3[a]

School code	Site code
22	1
	2
20	1
	2
13	1
	2
	3
21	1
	2
24	1
	2
11	1
14	1
	2
	3
17	1
2	1
	2[b]
	3
	4[c]
7	1
	2
	3
1	1
	2
	3
12	1
	2
19	1

a Classrooms and corridors with low friability, low asbestos content and moderate friability, or unknown asbestos content and moderate friability.
b Alternate, large student activity area used to replace this site.
c Site was selected for long-term sampling.

D. Sampling Period

Air sampling for this study was conducted during a period of approximately 4 weeks. Except at the long-term sites, air sampling was conducted for 5 consecutive school days at each site when possible. A randomization procedure was used to determine the order for monitoring the 22 schools that did not contain long-term sites. For operational efficiency, the schools were first paired according to location. The pairs were then randomly ordered, and this determined the order of field visits to the schools for air sampling.

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APPENDIX B

PROTOCOL FOR AIR SAMPLING

PROTOCOL FOR AIR SAMPLING

Airborne asbestos sampling will be conducted according to the general procedure outlined by Price et al. (1980). This will involve samples taken at each site (room or hallway) as designated by the site selection team. In addition, one outside ambient sample and one inside control sample (at a site chosen under the guidance of the selection team) will be taken at each group of sites (building). Field and laboratory blanks will be taken and analyzed for quality control.

Each sample system will be equipped with automatic timers and set to operate during hours of normal school activity (0730 to 1530) over a period of five consecutive school days, and the sample rate will be 5 L/min. The collection substrate will be 0.45-µm, 47-mm Millipore HA cellulose acetate membrane filters.

I. SELECTION OF SAMPLE LOCATION

A. Inside Samplers

Once a site has been identified, the indoor sample system is placed, within practical constraints, so as to collect a representative sample of the entire site. The filter is to be placed at a height of 1.5 m and in the least conspicuous location possible in order to minimize disruption of normal activity. The sample should not be located in a high activity area (doorway), within 2 ft of a wall or within 5 ft of a window. (Typically, a sample is placed on a table in the back of a classroom or on a table against the wall at the midpoint of a hallway.) Attention should also be given so as to ensure that the sampler in operation does not create an unsafe situation (e.g., extension cord across a doorway).

B. Outside Ambient Sampler

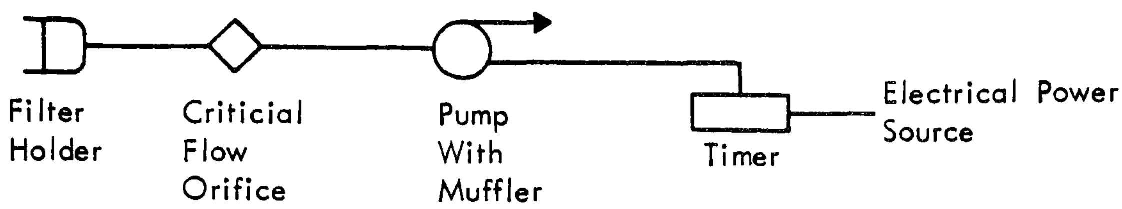
The location of the outside ambient sampler is important in obtaining a representative background measure. The sampler, thus, should be placed upwind of the building it is to represent such that no bias is created by identifiable local sources (parking lots, highways, building exhaust). With regard to the above considerations, as well as power requirements and anticipated accessibility to vandals, the upwind side of a building roof may be the most desirable location.

II. SAMPLE SETUP

The sampling system consists of:

1. A Gelman magnetic-type open-face filter.
2. A critical flow orifice.
3. A pump with muffler.
4. Associated plumbing and stand.
5. A 7-day timer.

The sampler setup is schematically represented as follows.



III. PROTOCOL

1. Clean and dry filter holder.

2. Place filter in holder, assuring proper position (see filter handling section).

3. Mount filter holder such that filter is in a vertical position (perpendicular to ground).

4. Check plumbing for any leaks.

5. Check flow with flowmeter using manual control of pump.

6. Set automatic timer to desired on-off time settings.

7. Make appropriate logbook entries.

8. Conduct sampling.

9. After sampling period, check flow.

10. Remove filter and place in Millipore petri dish for proper handling and transport.

IV. FILTER HANDLING

During loading and unloading of the filter holder, the filters are handled by forceps (not with fingers). When a filter is removed after exposure, it is placed in the petri holder exposed side up and maintained in that position during the handling and transport of samples back to the laboratory. The samples will be hand-carried to Battelle Columbus Laboratories by Battelle field personnel in a container that will keep the petri dish in a horizontal (flat) position at all times (handling, transport, and storage).

The MRI field test leader will give the filters that are collected by MRI field personnel to the Battelle field crew chief. The Battelle crew chief will place the samples in a shipping container and transport them to the Battelle Columbus Laboratories.

The chain-of-custody system will be followed at all times. A chain-of-custody record, therefore, will be kept on each filter (or sample).

One field blank will be randomly selected at each location. Any dropping or mishandling of a filter after collection must be recorded. Each filter holder is labeled according to a coding system.

V. LOGBOOK ENTRIES

An important part of any successful field program is the accurate observations and records of the field team. At a minimum, logbook entries will include:

1. Name of field operator.
2. Date of record.
3. Number and location of site.
4. Position of sampler within site.
5. Brief description of site.
6. Corresponding filter number.
7. Sample flow rate at start of sampling period.
8. Start time.
9. Stop time.
10. Sample flow rate at end of sampling period.
11. Comments.

REFERENCES

Price B, Melton C, Schmidt E, Townley C. 1980. Battelle Columbus Labs. Airborne asbestos levels in schools: a design study. Report. Washington, DC: Office of Pesticides and Toxic Substances, U.S. Environmental Protection Agency. Contract 68-01-3858.

APPENDIX C

PROTOCOL FOR CREATING AND MAINTAINING CHAIN OF CUSTODY

PROTOCOL FOR CREATING AND MAINTAINING CHAIN OF CUSTODY

The objective of this protocol is to establish a chain of custody for the handling of samples, from which the results may be introduced as evidence in legal proceedings. The chain-of-custody protocol described is based on MRI's standard laboratory practice for the handling of field samples. The manner in which the chain of custody is maintained may be altered by the project monitor.

Whenever physical evidence is introduced in a trial, it must be shown conclusively that the evidence introduced is in fact the evidence taken at the scene (in the field). The results of chemical analysis of a sample may be considered physical evidence and must be accounted for, back to the taking of the original sample. If necessary everyone who was in possession of the sample may be required to testify.

The chain of custody, then, consists of everyone who has possession of a sample. The chain of custody begins with the person who collects the sample. The person doing the sampling must actually collect, or witness the collection of, the sample. The sample is then labeled with the following information: a unique identifying code, the date of collection, the exact time of collection, and the sampler's signature. If a field logbook is being used, it should be bound. The identifying number, location, date, time, and description of the sample are entered in ink, as is the signature or initials of the person entering the foregoing data for each sample. A chain-of-custody form is also filled out in ink showing the sampler as having received the sample. From this point the sampler must be the only person with access to the sample until it is released to the next link in the chain of custody. A good system is to place the sample in a locked container or the trunk or interior of a vehicle, which must remain locked when the sampler is not present. The person having custody of the sample should retain possession of the keys. If the person having custody of the sample relinquishes custody, it must be noted on the chain-of-custody form, and the person receiving custody must note receipt on the chain-of-custody form.

The Battelle crew chief will be responsible for all air samples taken by the Battelle field crew. Samples taken by the MRI field crew will be given to the Battelle crew chief as soon as possible after the samples have been taken. The Battelle crew chief is totally responsible for sample custody upon transfer of the MRI collected samples.

I. SAMPLE TRANSPORT

When samples are transported from the field to the laboratory, the shipping container shall be securely fastened. Before closing the container, the original copy of the chain-of-custody form is signed and enclosed. If possible, the container should be transported by a method in which everyone receiving custody of the container must sign for it.

The air samples (filters) that are collected will be hand-carried by Battelle field crew personnel to Battelle Columbus Laboratories where they will be analyzed. These samples will be kept in a horizontal position at all times.

When the container arrives at the laboratory, a quality control representative, not the person who will be preparing the samples, will take custody of it. The quality control representative first examines the shipping container for any evidence of damage or tampering. After a check of the outside of the container, the examiner opens the container and checks each sample. The quality control representative shall note any damage or indication of tampering on the enclosed chain-of-custody forms and shall sign them. The shipping invoice showing everyone who received the container will be attached to one of the chain-of-custody forms.

The quality control representative has sole custody of the sample until it is relinquished, though someone else may examine or prepare the sample for analysis in full view of the quality control representative. A requirement here is a locked storage area to which only the person having custody has access. Notes concerning changes, manipulations, and storage conditions should be entered in ink in the logbook, initialed, and dated.

Whenever custody of the sample is transferred from one person to another, the person relinquishing custody of the sample must sign the chain-of-custody form and note the time and date of the transfer. The person receiving the sample must do the same. The person having custody of the sample has sole control of access to the sample.

APPENDIX D

PROTOCOL FOR THE SAMPLING AND ANALYSIS OF INSULATION MATERIAL SUSPECTED OF CONTAINING ASBESTOS

PROTOCOL FOR THE SAMPLING AND ANALYSIS OF INSULATION MATERIAL SUSPECTED OF CONTAINING ASBESTOS

Bulk samples of asbestos-containing material will be taken after air sampling is completed at a site. The specific points where these samples will be taken will be designated by the statistician at Research Triangle Institute who was involved in the air sampling survey design.

I. SAMPLING

The bulk sampling procedure will be based on that presented in EPA document entitled "Asbestos-Containing Materials in School Buildings--Guidance for Asbestos Analytical Programs" (USEPA 1980). Three sampling points will be selected from each air sampling site; two samples taken side by side at one of the three points provide a duplicate for quality assurance. This procedure eliminates the necessity of splitting samples at a later time.

An identification number will be assigned to each sample. This number will also appear on the sampler container, in the field logbook along with descriptive information, and on the chain-of-custody records. These numbers will be sent to the field on preprinted replicate gum labels that have other pertinent information on them.

II. SAMPLE HANDLING

The samples will be shipped by the field crew to the attention of the quality control representative at MRI, who will log them in and assign them permanent numbers on a random basis. The quality control representative will then identify and remove the duplicates and, from this set of duplicates, choose, on a random basis, a number of them for analysis by an external laboratory. The remaining duplicates will be put back with the remaining samples, and all of these will be given to the MRI analyst for analysis. The basis for the number of duplicate samples to be sent to the external laboratory is given later in this protocol under Quality Assurance.

III. ANALYSIS

The samples will be analyzed by polarized light microsocpy including dispersion staining. The procedure will closely follow that given in The Asbestos Particle Atlas (McCrone 1980). The procedure is summarized in Figure D-1. Quantitation of the asbestos content of the samples also will follow the procedure given in The Asbestos Particle Atlas.

IV. QUALITY ASSURANCE

Of the three bulk samples taken from each sampling site, one of the samples will be taken in duplicate for quality assurance.

Of the duplicate quality assurance samples, a number equal to 20% of the first 100 samples (not including the duplicates) and 10% of the remainder will be selected at random for analysis at a laboratory other than MRI. The remaining duplicate samples will be analyzed at MRI. All samples for analysis will have no identification other than the random identification number (OTS-XXXX).

<table>
<tr><td colspan="6">MOUNT A REPRESENTATIVE SAMPLE IN CARGILLE HIGH DISPERSION LIQUID n_D = 1.550</td></tr>
<tr><td>ISOTROPIC</td><td colspan="5">ANISOTROPIC</td></tr>
<tr><td rowspan="3">GLASS WOOL (106)[a]
Straight uniform diameter cylinders, λ_0 > 700 nm

MINERAL WOOL (111)
"Exotic" shapes, fibers variable n (1.50-1.70)

PUMICE (226)
Fire-polished flakes with vesicles, λ_0 >> 700 nm

PERLITE (529)
Thin glass films, foamed glass bubbles, λ_0 >> 700 nm

DIATOMS (5)
Organized, pitted, flat, sometimes elongated, λ_0 >> 700 nm</td><td colspan="2">FIBROUS</td><td colspan="3">NON-FIBROUS</td></tr>
<tr><td colspan="2">CHRYSOTILE (122)
λ_0 = 600-700 nm (blue $\perp$ length; 500-600 ($\parallel$)

WOOD FIBERS (70-73)
Blue ($\perp$ length), yellow ($\parallel$ length), pitted

POLYESTER (100)
Cylindrical, high birefringence $n_{\parallel}$ = 1.71, $n_{\perp}$ = 1.54

n's > 1.55 (pale yellow colors)
Mount in 1.605 HD liquid</td><td rowspan="2">λ_0 700 nm)
(pale blues)

GYPSUM (151)
Low birefringence, often tabular with oblique extinction</td><td rowspan="2">λ_0 Colors in visible

QUARTZ (183)
Glassy flakes, ω (blue), ϵ (blue-magenta)

LIZARDITE (710)
Lamellar aggregates, undulose extinction, blues and magentas

ANTIGORITE (117)
Yellow ($\parallel$) to golden magenta ($\perp$) rods

VERMICULITE (207)
Very thin sheets, nearly isotropic, λ_0's in yellow, turned up edges usually give blue crosswise, yellow lengthwise but n's vary</td><td rowspan="2">λ_0's < 400 (ω)
(pale yellows, white)

CALCITE (133)
Very high birefringence

DOLOMITE (140)
Like calcite, ω = 1.679

MAGNESITE (164)
Like calcite, ω = 1.694

TALC
Lamellar aggregates, pale yellows, plate view; blue ($\perp$ plate)</td></tr>
<tr><td>> 1 λ_0 < 700 nm

TREMOLITE (205)
Oblique extinction view (15-20°) usually shows yellow ($\parallel$) and blue ($\perp$); $\parallel$ extcn.: yellow ($\parallel$), magenta ($\perp$)

ANTHOPHYLLITE (121)
All views $\parallel$ extcn., usually pale yellow ($\parallel$); golden-yellow to blue-magenta ($\perp$)

ACTINOLITE (671)
Like tremolite, but all λ_0's < 450 nm

WOLLASTONITE (735)
Not so fibrillar, λ_0's (480-530 nm), (+) and (-) elongation</td><td>All λ_0's < 400 (yellows); mount in 1.68

AMOSITE (120)
Yellow ($\parallel$ length) magentas and blues ($\perp$ length), (+) elongation

CROCIDOLITE (123)
Yellow ($\parallel$ length), golden yellow ($\perp$ length), (-) elongation; pleochroic: gray-blue ($\perp$) and blue ($\parallel$) with one polar and no stops</td></tr>
</table>

a Particle Atlas Numbers, Vols II and III.

ALL DISPERSION COLORS GIVEN ARE FOR THE CENTRAL STOP

Figure D-1. Procedure for analysis of asbestos materials.

REFERENCES

McCrone WC. 1980. The asbestos particle atlas. Ann Arbor, MI: Ann Arbor Science, 122 pp.

USEPA. 1980. U.S. Environmental Protection Agency. Office of Toxic Substances. Asbestos-containing materials in school buildings: guidance for asbestos analytical programs. Washington, DC: USEPA. EPA 560/13-80-017A. PB81-24358 6.

APPENDIX E

ANALYTICAL PROTOCOL FOR AIR SAMPLES

ANALYTICAL PROTOCOL FOR AIR SAMPLES

Air samples will be analyzed by transmission electron microscopy (USEPA 1980). Select one filter from each box of 24 0.45-μm, 47-mm Millipore HA membrane filters to serve as a laboratory blank. Use all filters from the same production lot number, if possible. Prior to field sampling, determine if the laboratory blank filters are asbestos free by ashing followed by transmission electron microscope examination. Record filter box and lot number.

Upon receipt of filters from the sampling team, record in a laboratory logbook the sample numbers, date they were received, and any macroscopic identifying characteristics of particular filter samples. This includes damaged or smudged areas on the filter surface, lack of uniform sample deposition, unattached particulate or debris, unusually heavy-appearing deposit concentration, etc.

Measure precisely the diameter of the effective filter area. Mount on glass slides with double-sided adhesive any damaged areas removed prior to sample preparation and carefully measure. The total effective filter area and damaged areas of sample removed should be accurately recorded for purposes of calculation procedures.

In the original sample dish cut a 90° radial section of the original 47-mm filter sample with a clean, single-edged razor blade. Transfer the quarter section with stainless steel forceps to a clean, 1 x 3 in. glass slide, and cut again into smaller wedges to fit into the glass ashing tube (approximately 15 mm diameter x 150 mm long). Transfer the wedges by forceps to clean, numbered ashing tubes. Place the tubes in an LFE 504 low temperature plasma oven, one sample tube and one laboratory control tube per ashing chamber. The laboratory control tube may either contain a blank Millipore filter or be run as an empty tube. Maintain the ashing process at 450 watts for 2 hr.

Upon removal from the oven, treat the ashing tubes as follows. Place the tube in an ultrasonification bath. Pour 1 to 2 ml of 0.22-μm filtered Millipore-Q water into the tube from a clean 100-ml graduated cylinder. Sonicate (at 40 milliamperes) the sample vigorously for approximately 5 min and transfer it to a clean 150-ml glass beaker. Rinse the tube by additional ultrasonification two or three times more using a few milliters of filtered water each time, and transfer the contents to a 150-ml sample beaker. Add the remaining volume (up to 100 ml) of filtered water and sonicate again the entire suspended sample or blank, so that the total time of dispersion in the sonicator takes at least 20 min. Use a clean glass rod to stir the suspended sample while it is being sonicated.

Divide the 100-ml fraction into three aliquots: 10, 20, and 70 ml, prepared in that order. Using a 25-mm Millipore filter apparatus, place a 0.2-μm Nuclepore polycarbonate filter on top of an 8.0-μm mixed cellulose ester Millipore backup filter. Wet the filters by aspirating approximately 10 ml of filtered deionized water. Stop aspiration, pour in the first sample aliquot or portion thereof, and begin the aspiration procedure again. Carefully add the remaining sample volume without disturbing the flow across the Nuclepore filter surface. The suspended sample may be resonicated or stirred between filtration of the aliquots.

When the sample is deposited, carefully transfer the Nuclepore filter to a clean, labeled (sample number, date, and aliquot size) 1 x 3 in. glass slide Discard the Millipore backup filter.

When dry, attach the 0.2-µm Nuclepore filter tautly to the slide with transparent tape. Coat the filter with an approximately 40-nm-thick carbon film (National Spectroscopic Laboratories carbon rods) by vacuum evaporation. The film thickness need be sufficient only to provide support for the deposit sample.

Transfer the polycarbonate filter deposit to a 200-mesh electron microscope copper grid (E. F. Fullam) by first cutting a 3-ml-square portion from the filter using a clean, single-edged razor blade. Place this deposit side down on the electron microscope (EM) grid which, in turn, has been set upon a small, correspondingly labeled portion of lens tissue paper. Place the film, grid, and lens paper on a Jaffe dish consisting of a copper screen supported on a bent glass rod in a covered 90-mm glass petri dish. Pour reagent grade chloroform (J. T. Baker Company) into the dish to saturate the lens paper without submersing the grid and sample. Keep the dish covered at room temperature for 2 hr. Shift the prepared sample to a clean petri dish with fresh chloroform. Heat to 40°C for 10 min to provide a washing procedure.

While it is still wet, place the sample grid in a small gelatin capsule. Tape the capsule to the slide that has the remaining coated polycarbonate filter, and store until analysis.

Starting with the 70-ml fraction filter, examine the EM grid under low magnification in the transmission electron microscope to determine its suitability for high magnification examination. Ascertain that the loading is suitable and is uniform, that a high number of grid openings have their carbon film intact, and that the sample is not contaminated excessively with extraneous debris or bacteria.

Scan the EM grid at a screen magnification of 20,000X. Record the length and breadth of all fibers that have an aspect ratio of greater than 3:1 and have substantially parallel sides. Observe the morphology of each fiber through the 10X binoculars and note whether a tubular structure characteristic of chrysotile asbestos is present. Switch into selective area electron diffraction (SAED) mode and observe the diffraction pattern. Note whether the pattern is typical of chrysotile or amphibole, ambiguous, or neither chrysotile nor amphibole. Use energy dispersive X-ray analysis where necessary to further characterize the fiber. Take pictures as desired representing the sample type, fiber/particulate distribution, or characteristic SAED patterns of chrysotile and specific amphibole types.

Count the fibers in the grid openings until at least 100 fibers, or the fibers in a maximum of 10 grid openings, have been counted. Once counting of fibers in a grid opening has started, the count shall be continued though the total count of fibers may be greater than 100.

To ensure uniformity of grid opening dimensions, examine several 200-mesh grids by optical microscopy and measure roughly 10 openings per grid. Average these dimensions to provide a standard grid opening area.

Calculate from the following equation fiber number concentration expressed as the total number of fibers/original filter.

$$\text{Fibers/m}^3 = \text{number of fibers counted [area factor*][Nuclepore dilution factor x Millipore section dilution factor]} \quad \frac{1}{\text{volume, m}^3}$$

Calculate fiber mass for each type of asbestos in the sample by assuming that the breadth measurement is a diameter; thus, the mass can be calculated from

$$\text{Mass } (\mu g) = \frac{\Pi}{4} \cdot (\text{length, } \mu m) \cdot (\text{diameter, } \mu m)^2 \cdot (\text{density, g/cm}^3) \cdot 10^{-6}$$

The density of chrysotile is assumed to be 2.6 g/cm^3, and of amphibole, 3.0 g/cm^3. The mass concentration for each type of asbestos is then calculated from

$$\begin{array}{c}\text{Mass Concentration}\\ (\mu g/m^3) \text{ of a}\\ \text{Particular Type}\end{array} = \frac{\begin{array}{c}\text{Total Mass of All}\\ \text{Fibers of that Type } (\mu g)\end{array}}{\text{Volume of Air Sampled } (m^3)}$$

Record the fiber bundles and clusters as such, but do not include them in the mass calculation or the fiber count. Three reasons for not counting the fiber clusters and fiber bundles in the mass calculation are as follows: (1) it is difficult to assign the third dimension to the two-dimensional observation of the aggregates; (2) it is difficult to determine void space within bundles and clusters; and (3) since the bundles and clusters make up about 2% of the item count, one cannot be certain of the even distribution throughout the filter. The calculation assumes even distribution because to go from the counted area to filter area is a factor of about 10^6 depending on how many grid openings are actually counted.

REFERENCE

USEPA. 1978. U.S. Environmental Protection Agency. Office of Research and Development. Electron microscope measurement of airborne asbestos concentrations: a provisional methodology manual. Research Triangle Park, NC: USEPA. EPA 600/2-77-178.

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* $$\text{Area Factor} = \frac{\text{Total Effective Filter Area, cm}^2}{\text{Average Area of an EM Grid Opening, cm}^2}$$

APPENDIX F

FRIABLE MATERIAL SITE-SPECIFIC RATING FORMS

RATER'S NAME: ______________________________ DATE: __________________

Specific Site Cover Sheet

Full Name of School:

____

Location of Site: ____

Circle one: a Site b Indoor Control

1. Room Dimensions:

   a. length: ________________________ feet

   b. width: ________________________ feet

   c. height: ________________________ feet

CIRCLE ALL THAT APPLY:

2. Where is the suspicious material located?

   a on an exposed ceiling
   b above a suspended ceiling
   c on the walls

CIRCLE ONE ANSWER FOR EACH OF THE FOLLOWING QUESTIONS:

YES NO 3. Is the room carpeted?

YES NO 4. Is the floor tile or linoleum?

YES NO 5. Is the floor wood?

YES NO 6. Is a suspended ceiling present?

7. Circle all types of cleaning practices that apply to the area of the site and the frequency for each.

a	Sweeping	1 never	2 monthly	3 weekly	4 daily
b	Wet Mopping	1 never	2 monthly	3 weekly	4 daily
c	Dry Mopping	1 never	2 monthly	3 weekly	4 daily
d	Vacuuming	1 never	2 monthly	3 weekly	4 daily

RATER'S NAME: ______________________________ DATE: ______________
Circle: Site or Control

ALGORITHM SCORING SHEET

SCHOOL NAME: ____

Room (number): ____

1. Condition (<u>CLEARLY CIRCLE ONE SCORE FOR EACH FACTOR</u>)

    0 no damage
    2 moderate damage
    5 severe damage

2. Accessibility

    0 not accessible
    1 rarely accessible
    3 accessible

3. Part of Air Moving System (Plenum)

    0 no
    1 yes

4. Exposure

    0 material is not exposed
    1 10% or less of the material is exposed
    4 greater than 10% of the material is exposed

5. Water Damage

    0 no water damage
    1 minor water damage
    2 moderate or major water damage

6. Activity or Movement

    0 none or low activity level
    1 moderate activity level
    2 high activity level

7. Friability

    0 not friable
    1 low friability
    2 moderate friability
    3 high friability

8. Percentage Asbestos

    0 1% or less
    2 greater than 1% and less than or equal to 50%
    3 greater than 50%

RATER'S NAME: ______________________ DATE: ______________

SCHOOL NAME: ______________________________________

Room (number): ____________________________________

QUESTIONNAIRE: Circle the appropriate response to each question.

YES	NO	1.	Is there any evidence of "fallout" by accumulation of debris on any horizontal surfaces?
YES	NO	2.	Is the material covered with paint or other type of protective or decorative coating?
YES	NO	3.	Is the material subject to vibration due to machinery, traffic, airplanes, etc?
YES	NO	4.	Is this material damaged or deteriorating?
YES	NO	5.	Is there evidence that water has degraded the integrity of the material?
YES	NO	6.	Is the coating material exposed?
YES	NO	7.	Is this material accessible?
YES	NO	8.	Is there normally activity in (or around) the inspection area that could cause deterioration of the coating material?
YES	NO	9.	Is the material located in an air plenum or air stream?
YES	NO	10.	Is the coating material friable?

For the next section, use a scale of A, B, C, D, to rate the degree to which each factor applies. A is used to indicate the lowest rating for any factor while D is used to indicate the highest rating possible. Circle the letter which is applicable for each.

A	B	C	D	11.	Material condition (this factor includes deterioration due to water damage and other factors such as vandalism which have influenced the integrity of the material). A=excellent condition
A	B	C	D	12.	Exposed surface area. A=not exposed.
A	B	C	D	13.	How accessible is the material? A=not accessible.
A	B	C	D	14.	What is the normal level of activity in the inspection area? A=no activity.
A	B	C	D	15.	How friable is the material? A=not friable.

APPENDIX G

CLASSIFICATION ANALYSES BASED UPON THE 50TH PERCENTILE ($84\ ng/m^3$) OF THE AIRBORNE CHRYSOTILE DISTRIBUTION

Table G-1. Predicting Low/High Airborne Chrysotile Concentration with Three Regression-based Dichotomies

Distribution of the 48 Asbestos-containing Friable Material Sites: Observed Airborne Chrysotile Concentration Versus Predicted

Observed airborne chrysotile concentration (ng/m^3)	Predicted by seven algorithm factors[a] (Regression model I, Table 31) Low	High	Total
Low (≦ 68.6[b])	21	3	24
High (> 68.6)	18	6	24
Total	39	9	48

% Correct = 27/48 = 56.2%
Sensitivity = 6/24 = 25.0%

Observed airborne chrysotile concentration (ng/m^3)	Predicted by six algorithm factors[c] and releasability[d] (Regression model II, Table 31) Low	High	Total
Low (≦ 68.6)	19	5	24
High (> 68.6)	13	11	24
Total	32	16	48

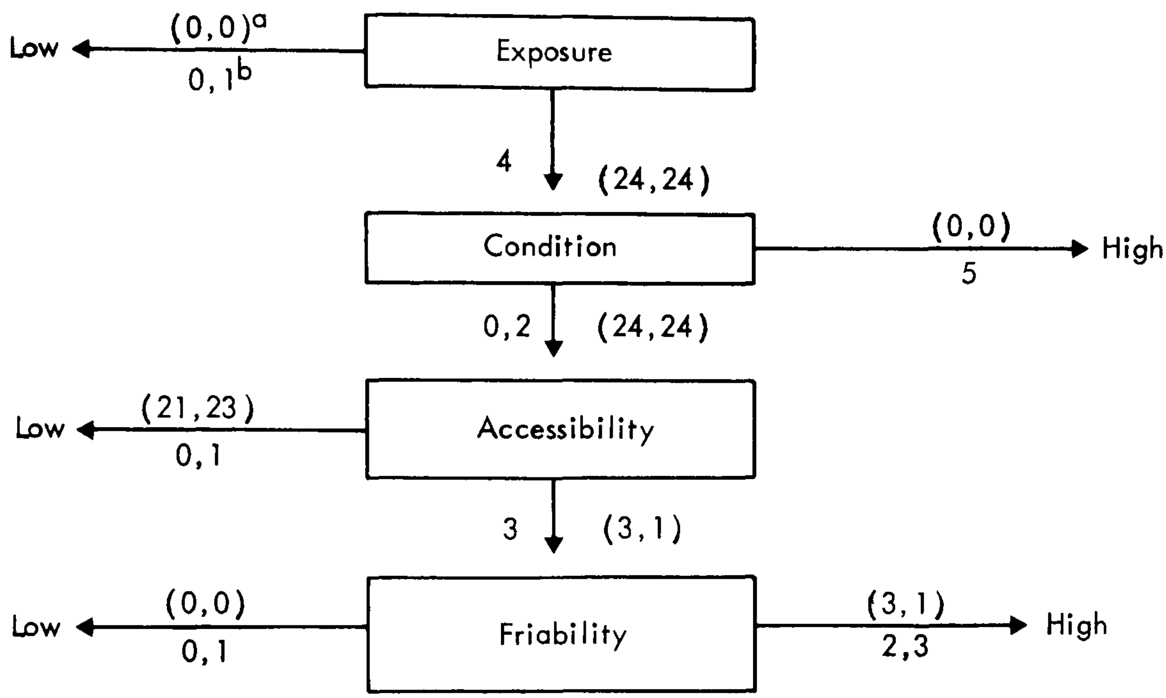
% Correct = 30/48 = 62.5%
Sensitivity = 11/24 = 45.8%

Observed airborne chrysotile concentration (ng/m^3)	Predicted by releasability,[d] room volume, and water damage (Unweighted regression model, Table 34) Low	High	Total
Low (≦ 68.6)	18	6	24
High (> 68.6)	11	13	24
Total	29	19	48

% Correct = 31/48 = 64.6%
Sensitivity = 13/24 = 54.2%

a Of the eight algorithm factors, exposure was not included because of zero variability. Bulk sample chrysotile content was included as the actual percentage instead of the original algorithm categorization.
b 68.6 ng/m^3 = 50th percentile for the 48 asbestos-containing friable material sites.
c Of the eight algorithm factors, exposure was not included because of zero variability, and friability was replaced by releasability category. Bulk sample chrysotile content was included as the actual percentage instead of the original algorithm categorization.
d Releasability category.

Table G-2. Predicting Low/High Airborne Chrysotile Concentration with the Original Decision Tree Based upon Proportion of Material Exposed, Material Condition, Accessibility, and Friability



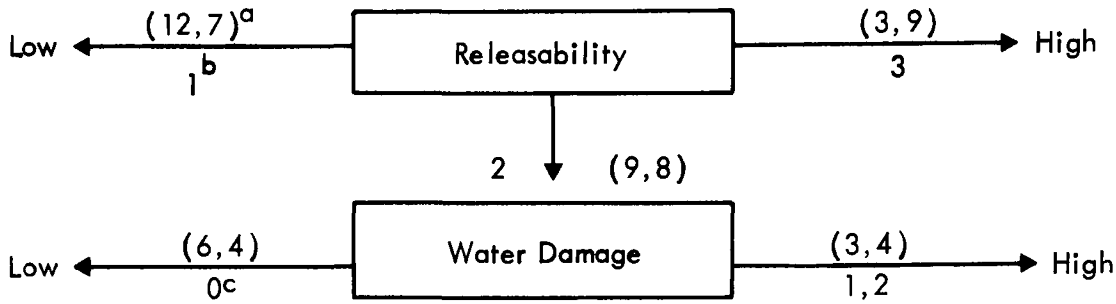
Distribution of the 48 Asbestos-containing Friable Material Sites: Low/High Airborne Chrysotile Concentration - Observed Versus Predicted by Decision Tree

Observed airborne chrysotile concentration (ng/m^3)	Predicted by tree: Low	Predicted by tree: High	Total
Low ($\leqq$ 68.6[c])	21	3	24
High (> 68.6)	23	1	24
Total	44	4	48

% Correct = 22/48 = 45.8%
Sensitivity = 1/24 = 4.2%

a Number of sites with low airborne chrysotile concentration ($\leqq$ 68.6 ng/m^3), number of sites with high airborne chrysotile concentration (> 68.6 ng/m^3).
b Algorithm factor codes.
c 68.6 ng/m^3 = 50th percentile for the 48 asbestos-containing friable material sites.

Table G-3. Predicting Low/High Airborne Chrysotile Concentration with a Decision Tree Based upon Releasability and Water Damage



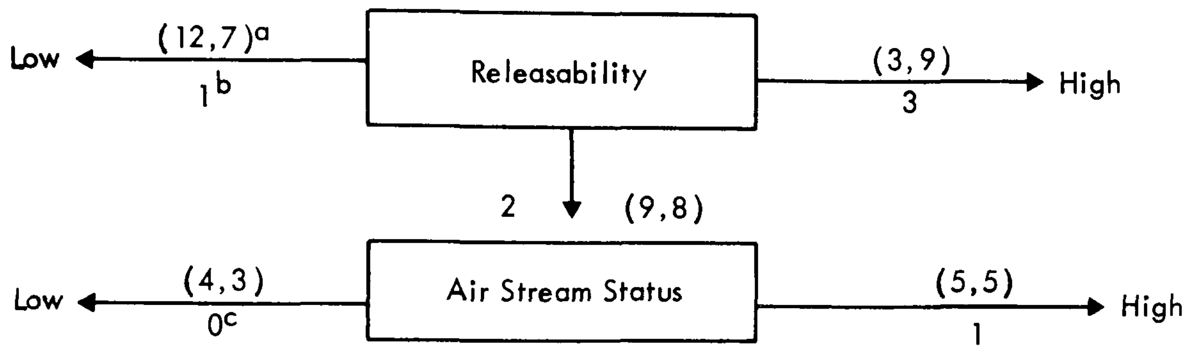
Distribution of the 48 Asbestos-containing Friable Material Sites: Low/High Airborne Chrysotile Concentration - Observed Versus Predicted by Decision Tree

Observed airborne chrysotile concentration (ng/m^3)	Predicted by tree		Total
	Low	High	
Low ($\leqq$ 68.6[d])	18	6	24
High (> 68.6)	11	13	24
Total	29	19	48

% Correct = 31/48 = 64.6%
Sensitivity = 13/24 = 54.2%

a Number of sites with low airborne chrysotile concentration ($\leqq$ 68.6 ng/m^3), number of sites with high airborne chrysotile concentration (> 68.6 ng/m^3).
b Releasability codes: 1 = ranks 1-4, 2 = ranks 5-6, 3 = ranks 7-9.
c Water damage codes.
d 68.6 ng/m^3 = 50th percentile for the 48 asbestos-containing friable material sites.

Table G-4. Predicting Low/High Airborne Chrysotile Concentration with a Decision Tree Based upon Releasability and Air Stream Status



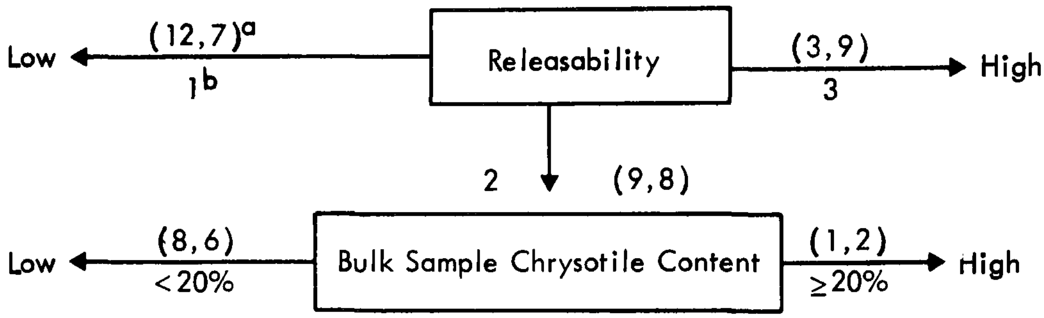
Distribution of the 48 Asbestos-containing Friable Material Sites: Low/High Airborne Chrysotile Concentration - Observed Versus Predicted by Decision Tree

Observed airborne chrysotile concentration (ng/m^3)	Predicted by tree Low	Predicted by tree High	Total
Low ($\leqq$ 68.6[d])	16	8	24
High (> 68.6)	10	14	24
Total	26	22	48

% Correct = 30/48 = 62.5%
Sensitivity = 14/24 = 58.3%

a Number of sites with low airborne chrysotile concentration ($\leqq$ 68.6 ng/m^3), number of sites with high airborne chrysotile concentration (> 68.6 ng/m^3).
b Releasability codes: 1 = ranks 1-4, 2 = ranks 5-6, 3 = ranks 7-9.
c Air stream status codes.
d 68.6 ng/m^3 = 50th percentile for the 48 asbestos-containing friable material sites.

Table G-5. Predicting Low/High Airborne Chrysotile Concentration with a Decision Tree Based upon Releasability and Bulk Sample Chrysotile Content



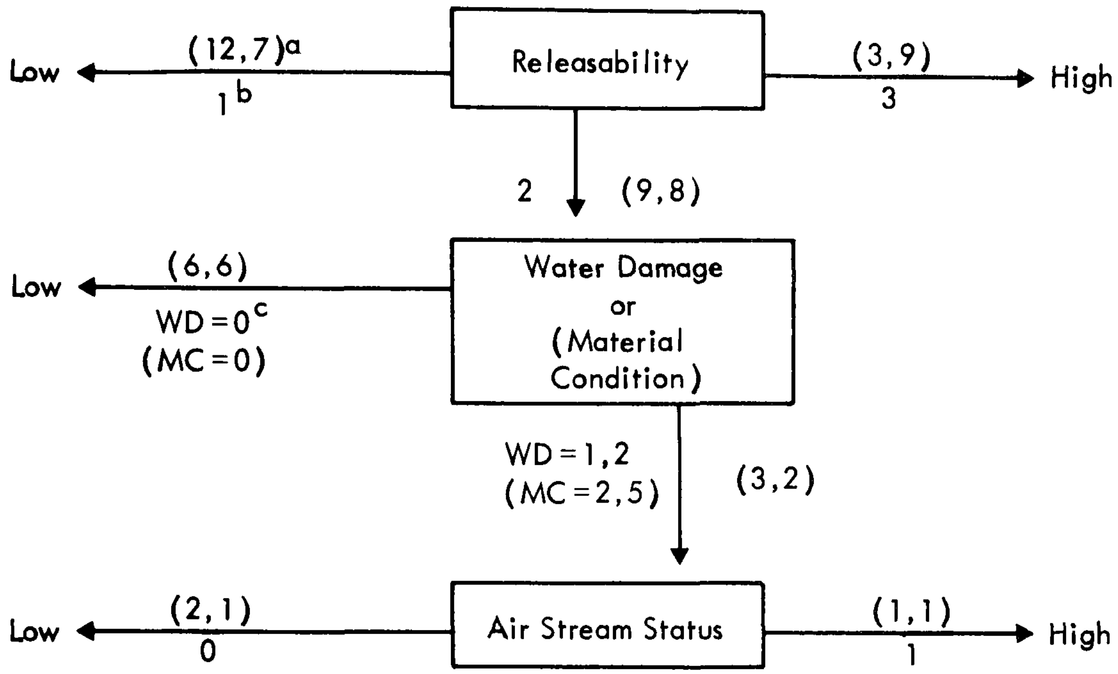
Distribution of the 48 Asbestos-containing Friable Material Sites: Low/High Airborne Chrysotile Concentration - Observed Versus Predicted by Decision Tree

Observed airborne chrysotile concentration (ng/m^3)	Predicted by tree		Total
	Low	High	
Low (≦ 68.6)	20	4	24
High (> 68.6)	13	11	24
Total	33	15	48

% Correct = 31/48 = 64.6%
Sensitivity = 11/24 = 45.8%

a Number of sites with low airborne chrysotile concentration (≦ 68.6 ng/m^3), number of sites with high airborne chrysotile concentration (> 68.6 ng/m^3).
b Releasability codes: 1 = ranks 1-4, 2 = ranks 5-6, 3 = ranks 7-9.
c 68.6 ng/m^3 = 50th percentile for the 48 asbestos-containing friable material sites.

Table G-6. Predicting Low/High Airborne Chrysotile Concentration with a Decision Tree Based upon Releasability, Water Damage (or Material Condition), and Air Stream Status



Distribution of the 48 Asbestos-containing Friable Material Sites: Low/High Airborne Chrysotile Concentration - Observed Versus Predicted by Decision Tree

Observed airborne chrysotile concentration (ng/m^3)	Predicted by tree: Low	Predicted by tree: High	Total
Low (≦ 68.6[d])	20	4	24
High (> 68.6)	14	10	24
Total	34	14	48

% Correct = 30/48 = 62.5%
Sensitivity = 10/24 = 41.7%

a Number of sites with low airborne chrysotile concentration (≤ 68.6 ng/m^3), number of sites with high airborne chrysotile concentration (> 68.6 ng/m^3).
b Releasability codes: 1 = ranks 1-4, 2 = ranks 5-6, 3 = ranks 7-9.
c Water damage and (material condition) codes.
d 68.6 ng/m^3 = 50th percentile for the 48 asbestos-containing friable material sites.

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15. Supplementary Notes

16. Abstract (Limit: 200 words) Air (116) and bulk (192) samples were collected from 48 units at 25 different schools of an urban independent school district. These were analyzed respectively by transmission electron microscopy and polarized light microscopy techniques for asbestos fiber concentrations. The new factor of releasability (of fibers) rating resulted from the bulk fiber analysis. Each sampling site was rated by a special five-person team for assessment tools: algorithm, condition, accessibility, part of air moving system, material exposure, friability and water damage, and people's activity at the site. The results were statistically analyzed to document potential exposure to airborne asbestos resulting from the friable, asbestos-containing material in schools and to develop an exposure assessment tool that would be based on the above stated factors. The principal conclusions related to the first study objective are: (1) airborne asbestos levels inside school buildings with asbestos are significantly higher than outdoor ambient levels due to the release of asbestos fibers from asbestos-containing materials inside those buildings; (2) within a school building, asbestos fibers are transported from rooms having asbestos-containing materials to rooms without these materials. The principal conclusions related to the second study objective are: (1) the existing algorithm is not a valid predictor of exposure to airborne asbestos levels; (2) the amount of asbestos in the bulk material is not a valid predictor of exposure to airborne asbestos levels; (3) the releasability rating system developed in this study is related to levels of airborne asbestos. (Additional studies are underway.)

17. Document Analysis a. Descriptors

Asbestos, asbestos sampling, asbestos analysis, asbestos algorithm, asbestos releasability, survey design, TEM, PLM

b. Identifiers/Open-Ended Terms

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